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of the
American Association *of* Petroleum Geologists

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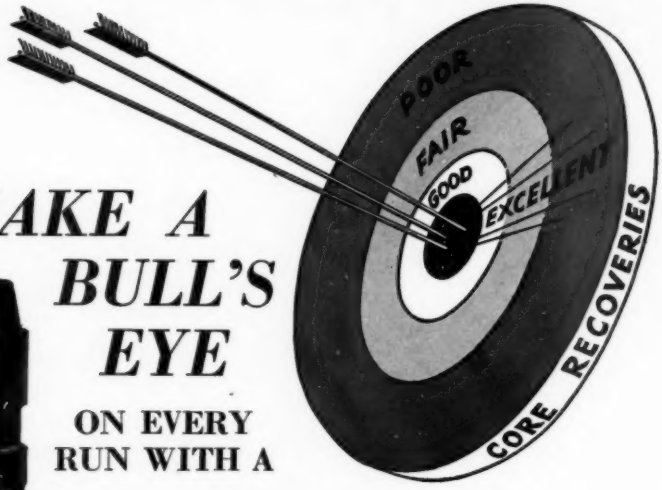

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THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers, $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

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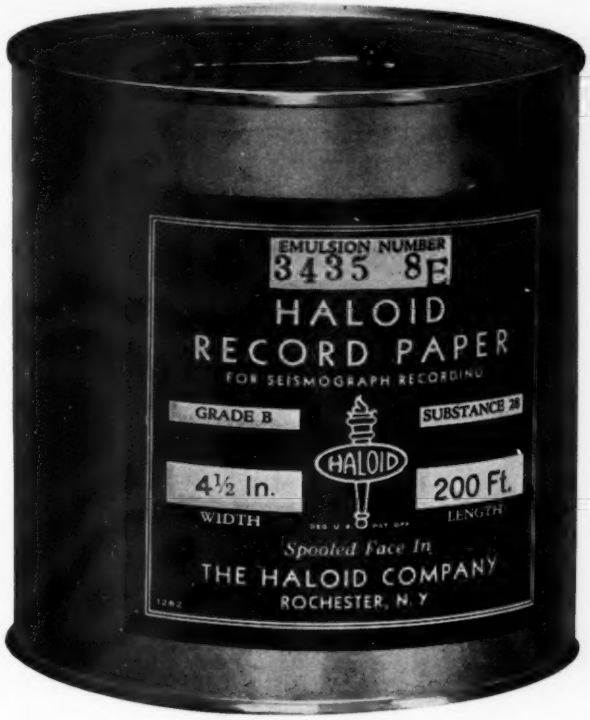

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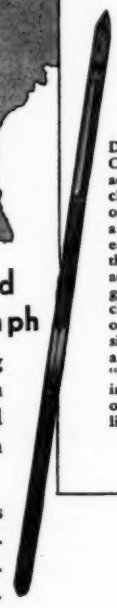

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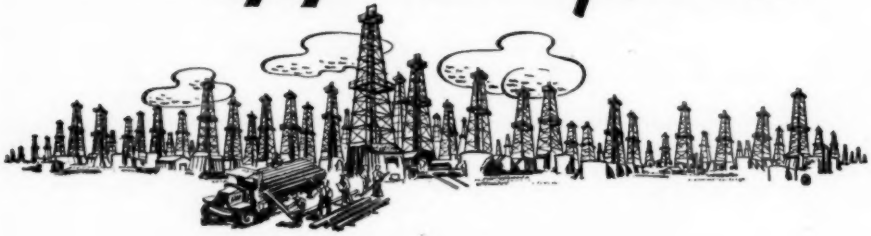

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BULLETIN
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FEBRUARY, 1939

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C. E. DOBBIN[2]
Denver, Colorado

ABSTRACT

The structural history, geologic structure, and results of deep drilling in an area occupying a structural transition zone between the High Plateaus of Utah and the Basin and Range Province are described. Cambrian quartzite rests unconformably on pre-Cambrian igneous rocks, and is overlain by as much as 20,000 feet of strata, which record frequent oscillations during the Paleozoic and Mesozoic, a period of uplift and erosion just prior to the Cretaceous, a period of orogeny during the late Cretaceous or early Tertiary (Laramide revolution), and post-Laramide thrust and normal faulting down to rather recent time. Major north-trending normal faults, with the downthrow on the west, divide the district into five east-dipping monoclinal blocks. The normal faults are both straight and curved, terminate abruptly, vary in vertical displacement along any one fault surface, and have as much as 4,500 feet of observable stratigraphic displacement.

Encouraged by the finding of oil in the small Virgin field 5 miles east and by the presence of anticlinal structure, six deep wells have been drilled in the district without discovering commercial quantities of oil or gas.

INTRODUCTION

This paper describes briefly the structural history, geologic structure, and the results of deep drilling in the southwest corner of Utah (Fig. 1). The results were obtained while investigating the oil and gas possibilities of that part of Petroleum Reserve No. 7 established in Washington County by President Taft in 1910.[3] As usable base maps of the district are not available, the investigation was mainly a detailed plane-table reconnaissance.

[1] Read before the Association at New Orleans, March 17, 1938. Published by permission of the director of the Geological Survey. Manuscript received, November 21, 1938.

[2] Geological Survey, United States Department of the Interior.

[3] M. W. Ball, "Petroleum Withdrawals and Restorations Affecting the Public Domain," *U. S. Geol. Survey Bull. 623* (1916), pp. 204–05.

ACKNOWLEDGMENTS

The writer is indebted to the following members of the Geological Survey: E. W. Henderson, for deep well information; W. B. Kramer, for the use of his detailed map of Bloomington dome; J. B. Reeside, Jr., for assistance with stratigraphic problems, and R. N. Doolittle and Ninetta Davis for drafting the illustrations. Acknowledgments for assistance in the field are made to Karl Walter, G. H. Cronin, and Robert McMillan.

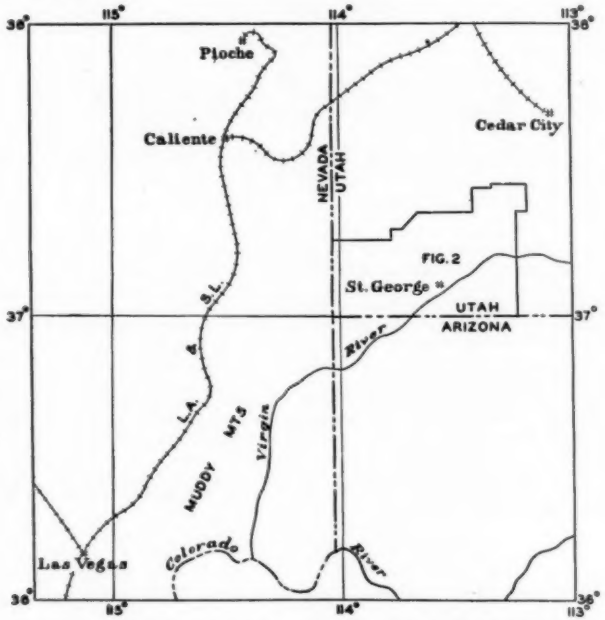


FIG. 1.—Index map showing location of area covered by Figure 2.

TOPOGRAPHY

The Hurricane Cliffs at the eastern border of the St. George district mark the boundary between the Great Basin on the west and the Colorado Plateaus on the east. Northeast of Toquerville the cliffs attain a maximum altitude in this area of about 5,800 feet, or 1,500 feet above the contiguous lands on the west (Fig. 10). Between Toquerville and LaVerkin the cliffs are lower and less distinct than on the north and south, consisting of a west-facing escarpment, attaining a maximum altitude of about 3,756 feet, and contiguous dissected hilly areas. South of LaVerkin to the Utah-Arizona State line the

cliffs are an almost straight, imposing wall rising abruptly above adjacent lowlands on the west (Fig. 7).

The Pine Valley Mountains attain a maximum altitude of about 10,000 feet and rise precipitously 3,000 feet above highly dissected and exceedingly rough areas lying south and east. High hogbacks of sedimentary rock, conspicuous outliers of lava, deep canyons, rough lava flows, alluvial fans sloping east, and valleys filled with waste occur between the mountains and the Hurricane Cliffs north and northeast of Leeds. The area south and southwest of the mountains is featured by deep canyons cut in gently dipping sedimentary rocks, broad lava flows sloping south, and one fairly level area—Diamond Valley—in or near which are several conspicuous cinder cones.

A conspicuous hogback of sandstone outlines the Virgin anticline and faces the superimposed Bloomington, Washington, and Harrisburg domes across lower lands of shale, gypsum, and alluvium. On the east limb of the anticline this hogback is bordered by a shale valley above which rises a sheer bluff of sandstone capped by a broad area of dune sand. This dune area gives way northeastward to a relatively flat area, featured by rough lava flows, waste-covered flats, and conspicuous cinder cones, across the north border of which Virgin River has cut an east-west canyon.

Northwest of Bloomington the sandstone forming the aforementioned hogback is the cap rock on a conspicuous escarpment as far as the Arrowhead Trail (U. S. Highway No. 91), northwest of which it forms a typical hogback. Here, as in other parts of the district, this sandstone dips beneath shale lowlands, above which stand precipitous bluffs of sandstone cut by deep, narrow canyons.

West of Bloomington and below the sandstone escarpment just described is a relatively low badlands area of gypsum and shale succeeded on the west by a broad dip slope of limestone terminated by a high fault scarp (Fig. 8). West and north of this fault scarp hogbacks of sandstone and limestone trend generally northward and are bordered on the west by the Beaver Dam Mountains. The Beaver Dam Mountains attain a maximum altitude of about 7,000 feet, and are featured by a core of relatively low hills, knobs, and peaks bordered on the east by high west-facing cuestas and on the west by alluvial aprons sloping gently westward into an intermontane basin occupying the western part of R. 19 W. and vicinity.

STRUCTURAL HISTORY

The 500 feet of unfossiliferous quartzite and quartz conglomerate patterned in Figure 2 represents initial Cambrian deposition on pre-Cambrian gneiss, schist, and granite near the eastern margin of the

deep and extensive Cordilleran geosyncline. Further progressive sinking of the geosyncline was followed by the deposition of as much as 235 feet of greenish, micaceous shale and 2,500 feet of dolomite and minor amounts of limestone which contain fragments of Upper Cambrian trilobites 165 feet above the base but seemingly no fossils above.

Although as much as 1,500 feet of fossiliferous but lithologically indivisible limestone, cherty limestone, and chert of Mississippian age crops out above the aforecited dolomite in the Beaver Dam Mountains, no clear evidence of a break between them was seen, except the somewhat abrupt change from dolomite to crinoidal limestone. Though faunal evidence suggests an interruption between Lower and Upper Mississippian, no physical data were obtained to corroborate this evidence.

Pennsylvanian time began with broad emergence of the land, which supplied material for as much as 150 feet of calcareous sandstone, variegated shale, and thin limestones that rest on Upper Mississippian limestone in the Beaver Dam Mountains. That resubmergence of the land soon followed, however, is shown by the superjacent 1,440 feet of indivisible, fossiliferous Pennsylvanian limestone. The entire sequence of Pennsylvanian strata probably represents the Callville limestone of Longwell.[4]

Regional uplift of the land following Callville time is manifested by the overlying 1,500-foot pale yellow Permian sandstone, with a variable deposit of gypsum at the base. The ensuing Middle Permian epoch was characterized by resubmergence and frequent oscillations, resulting in the deposition of alternating beds of marine limestone and gypsum comprising the 900-foot Kaibab limestone.

Here, as in broad contiguous areas, the transition from Paleozoic to Mesozoic was marked by a moderate emergence of the land, during which there was local channeling of the upper surface of the Kaibab limestone by subaerial forces.

During the Triassic the area received mainly continental deposits, sequentially included in the 2,000-foot Moenkopi formation, the 125-foot Shinarump conglomerate, and the 1,450-foot Chinle formation. Minor unconformities are present in this sequence, but the amount of time represented by them is unknown. Resubmergence of the district in part of Lower Triassic time is shown by the marine Virgin limestone member of the Moenkopi formation.

Desert conditions then followed, as indicated by the composition, cross-bedding, and other features of the 2,850-foot brownish and gray-

[4] Chester R. Longwell, "Geology of the Muddy Mountains, Nevada," *U. S. Geol. Survey Bull. 798* (1928), pp. 31–32.

white Navajo sandstone of probable Jurassic age. Following the deposition of the Navajo occurred the last subsidence of the district beneath marine waters, during which most of the 600-foot Upper Jurassic Carmel formation was deposited. Subsequent emergence of the land and the existence of swampy conditions are suggested by as much as 175 feet of overlying variegated beds.

After a break in sedimentation, during which the area of the Beaver Dam Mountains was uplifted and eroded, Upper Cretaceous time began with the deposition of a quartz and limestone conglomerate, as much as 50 feet thick, followed by the deposition of continental beds, as much as 3,200 feet thick, very near the western margin of the Upper Cretaceous interior area.

The next orogenic movements to affect the district occurred either in the late Cretaceous or early Eocene (Laramide revolution), resulting in local open folding along lines whose strike veers from northwest-southeast to northeast-southwest. Subsequently, the lacustrine Wasatch formation of Eocene age was deposited, locally overlapping rocks as old as the Navajo sandstone.

Since the Laramide revolution the district has been affected continually by crustal deformation and volcanic disturbances down to recent time, as indicated by thrust and normal faults of different ages, by extrusions of trachyte porphyry (Miocene?), and by faulted basalt flows, of Quaternary age, some of which are surmounted by well preserved cinder cones. Present information will not, however, admit of precise dating of most of these disturbances.

Since the deposition of the Wasatch formation, of Eocene age, the district has had a long arid cycle of highland erosion and basin deposition, as shown by the structure, composition and distribution of the torrential and playa deposits of Miocene (?) and younger ages found in the district.

STRUCTURE

As almost all the area lies west of the Hurricane fault—the dominant structural feature of southwestern Utah and northwestern Arizona—it falls within the Great Basin section of the Basin and Range Province, although structurally it occupies a transition zone between that section and the High Plateaus of Utah. In a broad way the area is divisible structurally into five east-dipping monoclinal blocks, separated in part by major north-trending normal faults with the downthrow on the west.

The faults in the area are both straight and curved, and terminate abruptly. Although some of the faults are the result of overthrusting

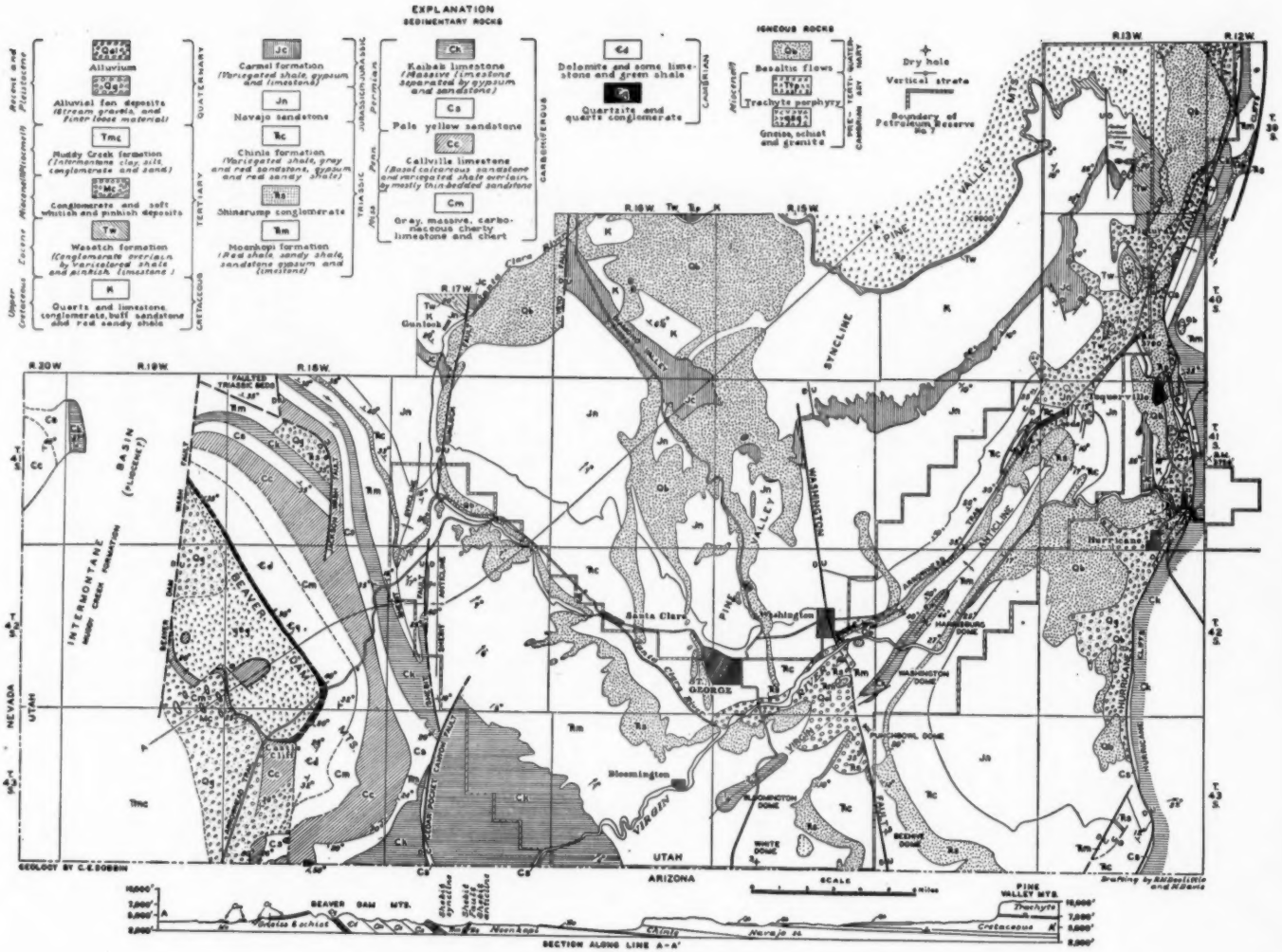


FIG. 2.—Geologic map of St. George district, Washington County, Utah.

from the west, most of them are normal and presumably resulted from relaxational movements along lines of weakness initiated by compression and later recurrent withdrawals of enormous amounts of lava. Subsequent faulting is clearly displayed locally in the Hurricane Cliffs and may be present elsewhere.

BEAVER DAM WASH FAULT BLOCK

The Beaver Dam Wash fault block occurs in Ts. 41 S. and 42 S., Rs. 19 W. and 20 W., west of the Beaver Dam Mountains. The surface rocks in the block are largely the unconsolidated and undisturbed Muddy Creek formation of Pliocene (?) age, through which east-dipping Callville limestone, sandstone of Permian age, and Kaibab limestone (Permian) project in T. 41 S., Rs. 19 W. and 20 W., on the east flank of the Mormon Range. The existence of the block is postulated principally because of the attitude of the aforementioned Paleozoic strata and the sudden westward termination against valley deposits in T. 41 S., R. 19 W., of the high mass of northwestward-striking Paleozoic and Mesozoic strata comprising the north end of the Beaver Dam Mountains. Whether the interrange valley occupying most of the block in Utah is a relatively simple depressed block now largely covered by the overlapping Muddy Creek formation or one containing a mosaic of fractures is unknown.

BEAVER DAM MOUNTAINS FAULT BLOCK

The Beaver Dam Mountains fault block embraces the area east of the Beaver Dam Wash fault and west of the Cedar Pocket Canyon, Shebit and Gunlock faults, including mostly the Beaver Dam Mountains, which are the northwestward end of the complexly faulted Virgin Mountains of Arizona and Nevada. Although the character and composition of the basal Cretaceous conglomerate just southwest of Gunlock and adjacent to Diamond Valley suggests that the area of the Beaver Dam Mountains experienced pre-Cretaceous uplift and erosion, the structural record of this event is obscured by later disturbances. Curved outcrops of Paleozoic and Mesozoic strata in and east of the Beaver Dam Mountains indicate that that area was folded into simple anticlinal form by tangential compression during the Laramide revolution. Thrust-faulting of probable Eocene and post-Miocene ages is present at and near Castle Cliff, and later normal faulting, of probable pre-Pliocene age, with the consequent blocking out of basins of continental deposition, is indicated by the presence of the undisturbed Muddy Creek formation, of Pliocene (?) age, in the intermontane area between the Beaver Dam Mountains and the

FIG. 2.—Geologic map of St. George district, Washington County, Utah.

FIG. 3.—Callville limestone (Pennsylvanian) thrust eastward over pre-Cambrian gneiss, schist, and granite 2 miles north of Castle Cliff, looking north. Contact of thrust plane and igneous rock along line *BB'*.

FIG. 4.—Callville limestone (Pennsylvanian) thrust eastward over basal Cambrian quartzite just east of Castle Cliff, looking south. Base of thrust plane along line *CC'*. Cambrian dolomite at *A*, Mississippian limestone at *B*, and Callville limestone at *D*.

Mormon Range. The present Beaver Dam Mountains, however, belong to the footwall of the assumed Beaver Dam Wash normal fault, the exact age and character of which are indeterminable.

Castle Cliff thrust.—As shown in Figure 2, at points along—and particularly south of—the Arrowhead trail, beginning about 2½ miles northeast of Castle Cliff, pre-Cambrian gneiss, schist, and granite are overlain by a normal sequence of Cambrian quartzite and quartz conglomerate (500 feet), Cambrian shale (235 feet), Cambrian dolomite and limestone (2,500 feet), Mississippian limestone (1,100± feet), and Callville limestone (1,500 feet), of Pennsylvanian age. However, at Castle Cliff, and points north and northwest therefrom, the Callville limestone (Pennsylvanian) rests on the pre-Cambrian gneiss, schist, and granite under conditions indicating an erosion thrust.

Fossils collected from the youngest limestones in the overriding Callville limestone block ½ mile southeast of Castle Cliff were identified by Girty as Pennsylvanian, whereas fossils collected at two lower horizons in that block directly above Castle Cliff were identified by him as Mississippian or Pennsylvanian. As the overriding block south of Castle Cliff is unbroken, as most of it is thin-bedded, and as early Pennsylvanian fossils occur in part of it, it is believed that the thrust plate is the lower part of the Callville limestone which originally rode eastward over a lubricating medium of basal Callville softer beds.

Between Castle Cliff and a point one mile east therefrom the overthrust sheet of the Castle Cliff thrust makes a north-facing wall of massive limestone which has sliced across Cambrian quartzite down to its base (Fig. 4). Good exposures of the contact of the overthrust sheet with the footwall block are lacking, however, because of débris. The attitude of certain limestone beds above the contact indicates that the thrust plane dips about 5° W. at this locality. South of the area just described the thrust is poorly defined—if present—in a small, unmapped area occupied by thick, indivisible Paleozoic sandstone and limestone with complex structure, and by relatively broad areas of waste.

Northwest of Castle Cliff the overriding sheet of Callville limestone crops out in low, narrow hogbacks, and in restricted areas of still lower exposures bordered by débris. As the strike of the overriding block is parallel to that of the axis of the Beaver Dam Mountains and as the block occurs in the western foothills, good exposures of all parts of it are generally lacking, especially clean exposures of the contact with the foot-wall block of gneiss, schist, and granite. Near the southwest corner of T. 42 S., R. 18 W., the overriding sheet dips as much as 25° SW., the stratigraphic displacement at the outcrop being as

much as 4,500 feet. Sudden termination of the sheet at several localities indicates disruption by both strike and dip normal faults.

About 2½ miles north of Castle Cliff the overthrust sheet forms a relatively high mass of limestone standing several hundred feet above its contact with gneiss, schist, and granite (Fig. 3). The thrust plane is concealed by débris, but the attitude of the hanging-wall block indicates that it dips about 10° SW.

Billings[5] has shown that in practically all examples of thrust faulting that have been described, older rocks rest on younger and that the conditions under which younger rocks may be thrust over older are not commonly understood. Longwell,[6] however, noted thrusting somewhat similar to that at Castle Cliff in the Mormon Mountains of southern Nevada and thought that the relations indicate erosion thrusting.

> Several miles to the east and directly north of the east-west fault there are thrust relations of a peculiar character. Two isolated hills are capped with Cambrian limestone and quartzite, which obviously have been pushed eastward over pre-Cambrian gneiss and schist along a flat surface. The sedimentary rocks are greatly brecciated and contorted, although the bedded structure is still recognizable. West and northwest of this location the same Cambrian formations are dropped down against the gneiss and schist on a steep fault with westward dip and north-south strike. It is believed that these relations indicate thrusting over an erosion surface of pre-Cambrian rocks, after which the north-south normal fault developed, and nearly all of the overthrust mass has been eroded from the upthrow side.

In the Pioche district, 80 miles northwest of Castle Cliff, Westgate and Knopf[7] found an overthrust sheet of Devonian dolomite and quartzite resting on limestones of Cambrian and Ordovician age, the dip of the fault plane being 8°–9° W.

In Mesquite Valley, southeastern California, Hewett[8] described a group of low hills made up of blocks of Lower Paleozoic (largely Cambrian) dolomite and shale that rest on a flat surface cut across pre-Cambrian granite gneiss. He states that

> Since these beds are normally underlain by about 1,200 feet of Cambrian shale, which in turn rests on 3,600 feet of early Cambrian dolomite and quartzite, and the beds dip steeply into the base of granite gneiss, it is clear that

[5] Marland Billings, "Thrusting Younger Rocks Over Older," *Amer. Jour. Sci.*, Vol. XXV (1933), p. 140.

[6] Chester R. Longwell, "Structural Studies in Southern Nevada and Western Arizona," *Bull. Geol. Soc. America*, Vol. 37 (1926), pp. 563–64.

[7] Lewis G. Westgate and Adolph Knopf, "Geology and Ore Deposits of the Pioche District, Nevada," *U. S. Geol. Survey Prof. Paper 171* (1932), pp. 42–43.

[8] D. F. Hewett, "Late Tertiary Thrust Faults in the Mojave Desert, California," *Nat. Acad. Sci.*, Vol. 14, No. 1 (1928), p. 9.

the blocks have been thrust from a distant westward source to their present position.

Because of the restricted area in which the Castle Cliff thrust crops out, the narrowness of most of its outcrops, and the presence of much débris, detailed evidence required to arrive at positive conclusions regarding the mechanics of its origin is unavailable. It seems plausible, however, to assume that it is a competent segment of the west limb of an anticline that was thrust eastward over an eroded surface of older rocks in Eocene time and dislocated subsequently by later normal faulting.

Post-Miocene (?) thrust faulting.—Two miles northwest of Castle Cliff, a conglomerate (Miocene?) of unknown thickness, and made up of cobbles of Paleozoic limestone and minor amounts of other Paleozoic rocks, dips about 10° E. and is overlain with irregular contact by large, disconnected blocks of brecciated, cherty limestone which also dip eastward (Figs. 5, 6). At intervals, to a distance of 2 miles farther west, similar disconnected limestone blocks rest with erratic dips and at various elevations on soft, whitish and pinkish deposits that may represent playa deposits of the same age as the limestone conglomerate. According to Girty, fossils collected from the limestone blocks are of early to Middle Mississippian age.

The large size of the limestone blocks and their structural relations to the underlying conglomerate and softer beds suggest that they are remnants of a once continuous sheet of Mississippian strata that was thrust over Miocene (?) alluvial and playa deposits previous to the deposition of the Pliocene (?) Muddy Creek formation and then cut by later normal faults. Many of the cobbles in the limestone conglomerate were derived from the Callville limestone, probably from the overriding block of the Castle Cliff thrust.

Relations similar to those just described have been reported by Hewett[9] in a ridge at the north end of Mesquite Valley, California.

> The ridge is made up of two parts, the base which is thin-bedded white volcanic ash trending generally N. 80° W., and dipping 60° to 80° N., and the apex which is a block of lower and upper Mississippian limestone about 3,000 feet long, 600 feet wide and 500 feet high. These beds trend slightly north of west, dip 70° north and about 600 feet of beds are present. The surface of contact of the Paleozoic limestones and underlying ash is clearly exposed for hundreds of feet on the south and north sides and on the east end. These exposures indicate that the upper block has the form of a huge ship which has been pushed out upon the beds of ash, probably from the west.

[9] *Op. cit.*, pp. 8–9.

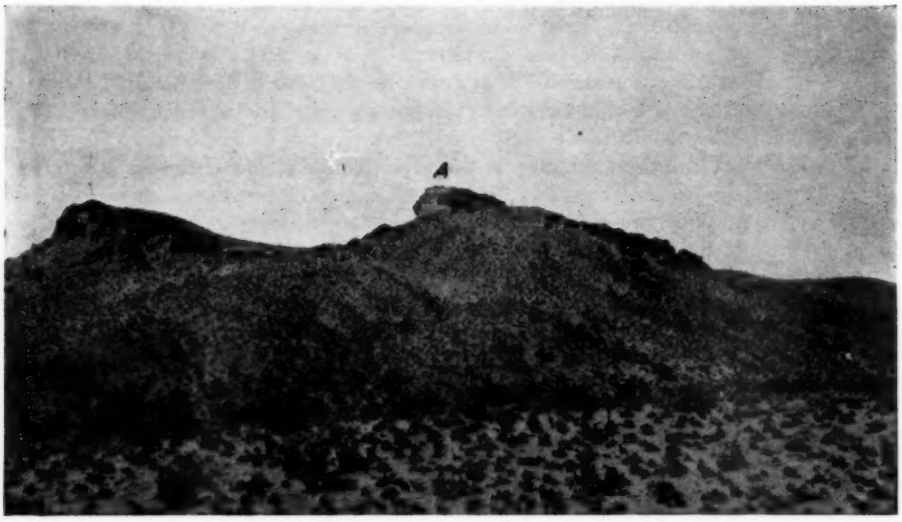


FIG. 5.—East-dipping Mississippian limestone on east-dipping limestone conglomerate (Miocene?), SE. ¼ of Sec. 26, T. 42 S., R. 19 W.

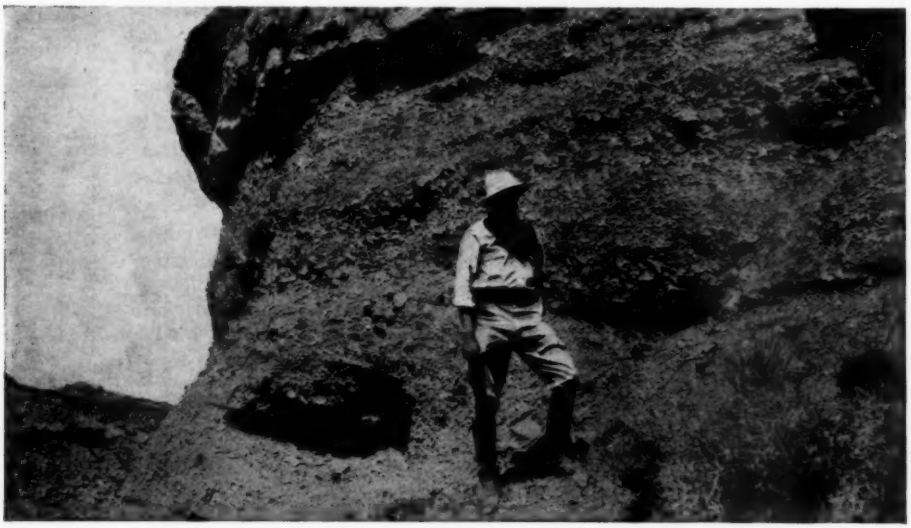


FIG. 6.—Nearer view of point *A* in Figure 5. (Robert McMillan, assistant.)

Hewett[10] has also shown that in the southern part of the Shadow Mountains, southeastern California, a block of pre-Cambrian granite gneiss rests on pale yellowish bentonite, volcanic ash, and gravels; that in the northern part of the Shadow Mountains numerous blocks of Cambrian sediments rarely more than 2,500 feet long and 350 feet thick, rest on ash and gravels; and that in a large area west of the Shadow Mountains there are numerous hills 200 to 500 feet high which show caps of either pre-Cambrian granite gneiss or Cambrian sediments resting on ash or gravels. He also concluded that these isolated blocks of gneiss and Paleozoic sediments are remnants of a once continuous sheet of rocks that were thrust over mid-Tertiary ash and gravels and broken by parallel normal faults before being greatly eroded.

Other faults.—Longitudinal faults within the Beaver Dam Mountains fault block, such as the Jackson Wash fault and others in R. 18 W., indicate differential movements within the block which are undated and which produce minor longitudinal ridges and valleys. The stratigraphic displacement of the Jackson Wash fault is nearly 5,000 feet and that of the intersecting fault north of it about 4,400 feet. Additional strike-faulting within this block is indicated by repeated outcrops of the Shinarump conglomerate and contiguous formations in and near the northwest corner of T. 41 S., R. 18 W., and by disrupted Paleozoic beds in and near the central part of T. 43 S., R. 18 W. Erratic dips and highly inclined strata also suggest that the east slope of the Kaibab limestone outcrop is locally affected by relatively minor faults west of the Shebit syncline, though these are not shown in Figure 2.

ST. GEORGE FAULT BLOCK

The west boundary of the St. George fault block is formed by the Cedar Pocket Canyon, Shebit, and Gunlock faults, and the east boundary by the Washington fault, which seemingly dies out in the northern part of T. 41 S., R. 15 W., leaving near the southwest end of the Pine Valley Mountains no well defined boundary between this block and the Leeds block on the east. The only upfolds of consequence in the block are the Shebit anticline in T. 42 S., R. 17 W., and a part of the Virgin anticline in T. 43 S., R. 15 W., and vicinity. Except at Bloomington dome, where steep dips in all directions occur, and on the east side of the Shebit fault, most of the strata in the block dip gently northeastward into the broad Pine Valley syncline, the axis of which passes through St. George and the central portion of the Pine Valley Mountains.

[10] *Op. cit.*, p. 10.

FIG. 7.—Upthrown block of Kaibab limestone along Hurricane normal fault in northern part of T. 43 S., R. 13 W. Note basalt spilled over cliff at *A*.

FIG. 8.—Cedar Pocket Canyon normal fault just north of Utah-Arizona boundary, looking south. Bed *A* at fault plane is bed *A'* in foot-wall block of Kaibab limestone and underlying Permian sandstone.

Cedar Pocket Canyon fault.—The Cedar Pocket Canyon normal fault enters Utah from Arizona in the south-central part of Sec. 32, T. 43 S., R. 17 W., and from there northward for about 4 miles is expressed topographically by a foot-wall block of Kaibab limestone and subjacent Permian sandstone standing in imposing relief above a hanging-wall block of Kaibab limestone and superjacent Moenkopi formation (Fig. 8). The displacement of the fault decreases rapidly northward and is apparently zero in the south-central part of T. 42 S., R. 17 W. Although the displacement occurs chiefly along a single fracture, a comparatively narrow zone of minor distributive faulting occurs just west of the main fracture, forming a complicated mosiac of Kaibab limestone blocks. The stratigraphic displacement of the main fault is locally decreased by dragging of the Kaibab limestone, but locally in Utah is as much as 1,200 feet, with the downthrow on the west. In common with most normal faults in this region, the fault plane is nearly vertical.

Shebit anticline and fault.—The Shebit anticline is an unclosed, north-plunging anticline in the small Shebit Indian Reservation, T. 42 S., R. 17 W. Lower beds in the Moenkopi formation are faulted relatively little on the axis of the fold, and on the east limb higher beds in that formation dip 7° NW. into the Pine Valley syncline. West of the anticlinal axis Moenkopi strata and the overlying Shinarump conglomerate locally dip as much as 60° into the reverse Shebit fault, along which locally the Shinarump abuts against a hogback of Kaibab limestone dipping 25° W. into the contiguous Shebit syncline, the stratigraphic displacement being as much as 2,350 feet. The throw of this fault decreases gradually northward until it has little or no displacement, but north of this area of no displacement it carries on with reversed throw as the Gunlock fault. Small subsidiary north-trending open folds occur just south of the highway and west of the Shebit fault.

Gunlock fault.—The Gunlock normal fault begins somewhat abruptly in the southwest part of T. 41 S., R. 17 W., and trends north-northeast with increasing displacement in an almost straight line across and beyond the area here described. Although the fault plane in locally concealed by a Recent basalt flow, the fault is clearly indicated by disrupted outcrops of the thick Navajo sandstone, which forms an imposing southwest-facing mountainous mass in the upthrown block. The greatest stratigraphic displacement of the fault in the area is nearly 4,000 feet in the SE. ¼ of Sec. 21, T. 40 S., R. 17 W., where the base of the Wasatch formation in the west or downthrown block abuts against a horizon about 100 feet below the top of the Navajo sandstone in the upthrown block.

Veyo fault.—The Veyo normal fault in the western part of T. 40 S., R. 16 W., is assumed because of the sudden termination of the upper part of the Navajo sandstone against a lower sheet of basalt and because of the offsetting of outcrops of the Carmel formation in that township with respect to equivalent outcrops in T. 41 S., R. 17 W. The structural details of the fault are, however, obscured by the basalt.

LEEDS FAULT BLOCK

The west boundary of the Leeds fault block is the Washington fault and the east boundary the Hurricane fault. The most conspicuous observable structural feature in the block is the Virgin anticline, the down-dropped southwest end of which is in the St. George fault block.

Washington fault.—The Washington normal fault is a relatively narrow zone of distributive faulting that begins in Cretaceous rocks near the southwest end of the Pine Valley Mountains and trends south with increasing displacement into Arizona. Although the fault is clearly indicated locally by disrupted outcrops of hard strata, such as the Shinarump conglomerate, the structural details are difficult to determine, because the west, or hanging-wall, block is generally covered by detritus in and near the shear zone. Where the fault enters Utah, the vertical Virgin limestone member of the Moenkopi formation in the foot-wall block abuts against fine detrital matter that probably covers an indeterminable horizon in the Chinle formation, the estimated stratigraphic displacement being 2,500 feet. North of the State boundary for several miles the Shnabkaib shale member of the Moenkopi is the lowest zone exposed in the upthrown block, abutting against coarse detritus in the downthrown block. Rotated blocks of Shinarump conglomerate and subjacent Moenkopi formation standing at different altitudes in the broad areas of cultivated alluvium south of Virgin River and many slices of Shinarump conglomerate just south of Washington indicate the presence there of multiple faults. Evidence of more than one fault was also observed in the dune area north of Washington.

Virgin anticline.—The Virgin anticline is a symmetrical, tilted, northeast-trending fold rimmed by a hogback of Shinarump conglomerate, featured by three domes of Kaibab limestone—Harrisburg, Washington and Bloomington—and cut by both strike and dip faults, the largest one of which (the Washington) has been described. Repeated outcrops of the Shinarump conglomerate and a conspicuous sandstone member of the Chinle formation indicate relatively minor

strike-faulting on the west limb of the anticline, west and southwest of Leeds, and fracturing occurs along the axis of the fold just east of Leeds. The nature and extent of all the faults northeast of Leeds are indeterminable, because of the detritus and basalt in the relatively depressed area traversed by the Arrowhead Trail. On the northwest limb of the anticline the beds dip progressively less toward the Pine Valley syncline, and on the southeast side, east of the Washington fault, they dip east beneath basalt flows and detrital matter extending to the Hurricane fault.

Harrisburg, Washington, and Bloomington domes are similar structurally and stratigraphically, each consisting of a relatively high core of Kaibab limestone standing well above encircling outcrops of the Virgin limestone member of the Moenkopi formation and higher Moenkopi beds. The domes are unsymmetrical—the dips on their northwest sides being as much as 70°, and those on the southeast flanks much less—and relatively small strike faults, contorted beds, and irregular dips are common.[11]

Pintura area.—The Leeds fault block northeast of Leeds and east of the outcrop of the Navajo sandstone is featured by dune sand, alluvial fans, talus, basalt flows, overlapping Wasatch formation, and isolated masses of extrusive trachyte porphyry, which probably conceal many faults. The Navajo sandstone and younger formations dip 30° and less into the Pine Valley syncline. The faults shown northwest and southwest of Pintura in Figure 2 are indicated clearly in the field by disrupted outcrops of the Carmel formation. Other faults believed to be present in the Navajo sandstone could not be identified easily because of the lithologic indivisibility of that thick unit.

HURRICANE CLIFFS FAULT BLOCK

The only part of the Hurricane Cliffs fault block herein considered is that part of its foot-wall comprising the Hurricane Cliffs. North of Toquerville the crest of the cliffs attains a maximum altitude of about 5,800 feet and stands as much as 1,550 feet above the highway (Fig. 10). Between Toquerville and LaVerkin the cliffs are less distinct and lower than elsewhere in this area, attaining a maximum altitude of nearly 3,775 feet. South of LaVerkin to the Utah-Arizona State line the cliffs are an almost straight wall of Kaibab limestone and contiguous formations rising abruptly above down-faulted lowlands on the west (Fig. 7). The west boundary of this fault block is the Hurricane

[11] Harvey Bassler and John B. Reeside, Jr., "Oil Prospects in Washington County, Utah," *U. S. Geol. Survey Bull. 726* (1922), pp. 99–103.

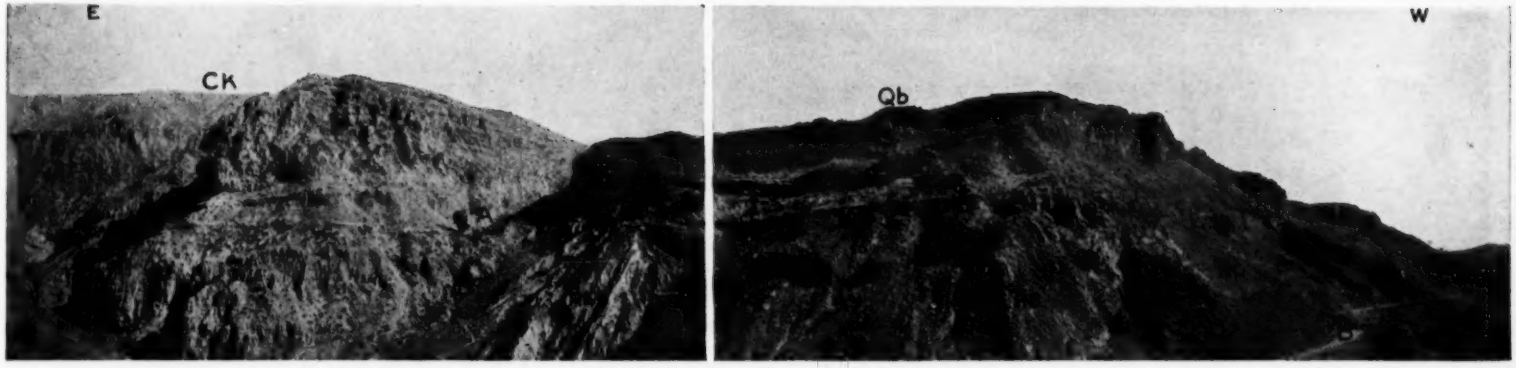


FIG. 9.—South bank of Virgin River Canyon south of LaVerkin, looking south. Old normal fault at *A*. Kaibab limestone in upthrown block; steeply dipping Moenkopi formation, Shinarump conglomerate, and Chinle formation in downthrown block covered by basalt. Recent normal fault displaces basalt about 260 feet down on west at *B*.

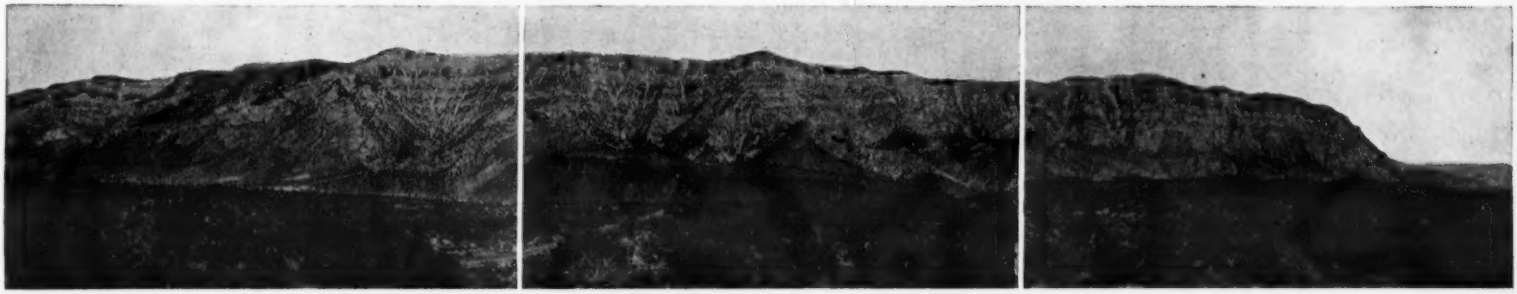


FIG. 10.—Hurricane Cliffs north of Toquerville. East-dipping Kaibab limestone on sky-line underlain in center and right by thick Permian sandstone. Beds at foot of scarp dip steeply west. Basalt flow on crest at left and at base of cliffs in center. Foreground is outwash.

fault, which is the west boundary of the high plateaus of Utah and concerning which Dutton[12] wrote:

> Of all the great dislocations of the western mountain region there is surely none so wonderful or more interesting.

Hurricane fault.—The Hurricane fault, according to Gregory,[13] extends from a point near Beaver, about 66 miles north of the St. George district, southward across Colorado River, its total length being about 200 miles. The structural and physiographic details of this master displacement along its entire length have not been described.

In the St. George district the Hurricane fault is not one clean, continuous fracture, but is, in part, at least, a zone of shearing along which recurrent offsetting movements of different character and intensity have occurred. The oldest of the fractures seen along the fault is that exposed at the hot springs in Virgin River canyon just south of LaVerkin. There a horizon 160 feet above the base of the gently east-dipping Kaibab limestone in the foot-wall block abuts against the base of the almost vertical Shnabkaib shale member of the Moenkopi formation in the hanging-wall block, the stratigraphic displacement being nearly 1,730 feet (Fig. 9). Sliced blocks in the canyon walls and isolated exposures of vertical Carmel formation half a mile west of the canyon mouth suggest that distributive faults are concealed beneath basalt west of the observable main fracture. No data on the age of this early fault were obtained, except that it is post-Cretaceous.

Recent normal faulting within part of the shear zone of the earlier faulting is shown at *B*, Figure 9, by the 260-foot displacement down on the west of a gravel-covered basaltic flow that covers part of the hanging-wall block of the old fault. Relatively minor breaks in the hanging-wall block of this Recent fault indicate still later crustal adjustments.

North of the Utah-Arizona boundary, almost to the town of Hurricane, the west face of the east or upthrown block of the Hurricane fault is an abrupt fault scarp of gently east-dipping Kaibab limestone and subjacent Permian sandstone standing in bold relief above the downthrown block (Fig. 7). In the SW.$\frac{1}{4}$ of Sec. 23, T. 43 S., R. 13 W., where the base of the Navajo sandstone abuts against the base of the Kaibab limestone, the stratigraphic displacement is about 4,565 feet. Additional frontal faulting in the hanging-wall block

[12] C. E. Dutton, "Tertiary History of the Grand Canyon District, *U. S. Geol. Survey Mon. 2* (1880), p. 112.

[13] Herbert E. Gregory, "Colorado Plateau Region," *Internat. Geol. Cong. Guidebook 18* (1933), p. 19.

near this locality is indicated by the abutting of the base of the Shinarump conglomerate against the base of the Navajo sandstone along a fault in the southern part of Sec. 21 of the same township, the stratigraphic displacement being about 1,600 feet. Minor fracturing also occurs in the face of the upthrown block. The extent, age, and character of the faulting along the Hurricane fault for a distance of 8 miles south of Hurricane could not be determined because basaltic flows and débris conceal bedrock in the hanging-wall block.

East and southeast of Toquerville part of the older displacement along the Hurricane fault is taken up by several short strike faults, with relatively small displacements, and minor flexing, with the result that a conspicuous fault-scarp is lacking. Recent faulting is indicated by a tilted basalt flow in the hill just east of Toquerville.

North of Toquerville the elevated foot-wall block of Kaibab limestone and contiguous formations is roughly anticlinal, probably representing flexing along the earlier fault. Faulting in rather recent times is suggested by the position of horizontal basalt flows on the crest of the Hurricane Cliffs with respect to their probable east-tilted equivalents along the Arrowhead Trail just west (Fig. 10), the displacement down on the west being about 1,500 feet. No fault planes were seen in this area, however, because of talus, stream gravel, and basalt.

The geologic history of the Hurricane fault in this district has been set forth by Huntington and Goldthwait,[14] their main conclusions being that since the first uplift of the district at the end of the Eocene the area now occupied by the Hurricane fault has had two periods of faulting, separated by a long interfault cycle of erosion—their Mohave peneplain—and that the present Hurricane scarp is the result of the later period of faulting.

HISTORY OF DRILLING

BLOOMINGTON DOME

The first deep test of Bloomington dome was made by the Mid-American Oil Company in the SE. ¼, NW. ¼ of Sec. 17, T. 43 S., R. 15 W. The drilling of this well (No. 2, Fig. 2; see also Fig. 11) was begun, January 30, 1927, drilling was suspended at 1,974 feet in July, 1929, resumed in March, 1930, and the well was abandoned at a depth of 2,530 feet in May, 1931.

The only other deep test of the Bloomington dome was the Escalante Explorations, Inc., well No. 2 (No. 1, Fig. 2; see also Fig. 11)

[14] Ellsworth Huntington and J. W. Goldthwait, "The Hurricane Fault in the Toquerville District, Utah," *Harvard Coll. Mus. Comp. Zoöl. Bull.*, Vol. 42 (1904), pp. 199–259.

DRILLERS' LOG OF ESCALANTE EXPLORATIONS INC. WELL NO. 2, NE. ¼ OF SEC. 19, T. 43 S., R. 15 W., BLOOMINGTON DOME, WASHINGTON COUNTY, UTAH

Depth in Feet	*Formation*
45*	Lime with shale breaks
75	Shale
100	Conglomerate
180	Alternating sands and shales
200	Lime
205	Shale
237	Lime
250	Lime and conglomerate
475	Lime
545	Alternating limes and shales
580	Black calcareous and sandy shales
675	Shale containing thin lime beds
677	Tar sand
690	Shale
693	Tar sand
730	Shale
732	Tar sand
770	Sand
790	Sandy shale
890	Lime containing thin sands
935	Sandy shale
1,227	Lime
1,260	Sand
1,330*	Sandy shales containing gypsum
3,085	Sand with lime streaks
3,120	Sand containing oil
3,170†	Sand with lime streaks
3,205	Sand with lime streaks and containing oil
3,316	Sand with lime streaks
3,345	Sand with lime and shale streaks and containing oil
3,360	Sand
3,365	Sand containing oil
3,390	Sand with lime streaks
3,400	Sand containing oil
3,520	Sand with streaks of lime
3,605	Sandy lime and lime containing oil
3,635	Lime
3,640	Sandy lime containing oil
3,710	Lime and shale containing sand streaks
3,715	Sandy lime containing oil
3,726	Lime
4,054	Lime
4,067	Red shale
4,086	Shale and hard shell
4,090	Hard sand
4,096	Hard lime
4,102	Red shale
4,114	Sandy white lime

* Rotary tools used from 0 to 4,044 feet, and from 4,057 to 4,098 feet. Cable tools used from 4,044 to 4,057 feet and from 4,098 to 4,114 feet.

† Water was encountered at some point between 3,140 and 3,726 feet; tests indicated about 3,175 feet.

in the NW. ¼, NE. ¼ of Sec. 19. Drilling was commenced May 13, 1931, and the well was shut down at 3,726 feet in about March, 1932. Later the Arrowhead Petroleum Corporation purchased 51 per cent of the stock and resumed drilling August 11, 1933, reaching in December, 1934, a depth of 4,114 feet. In attempting to shoot the well

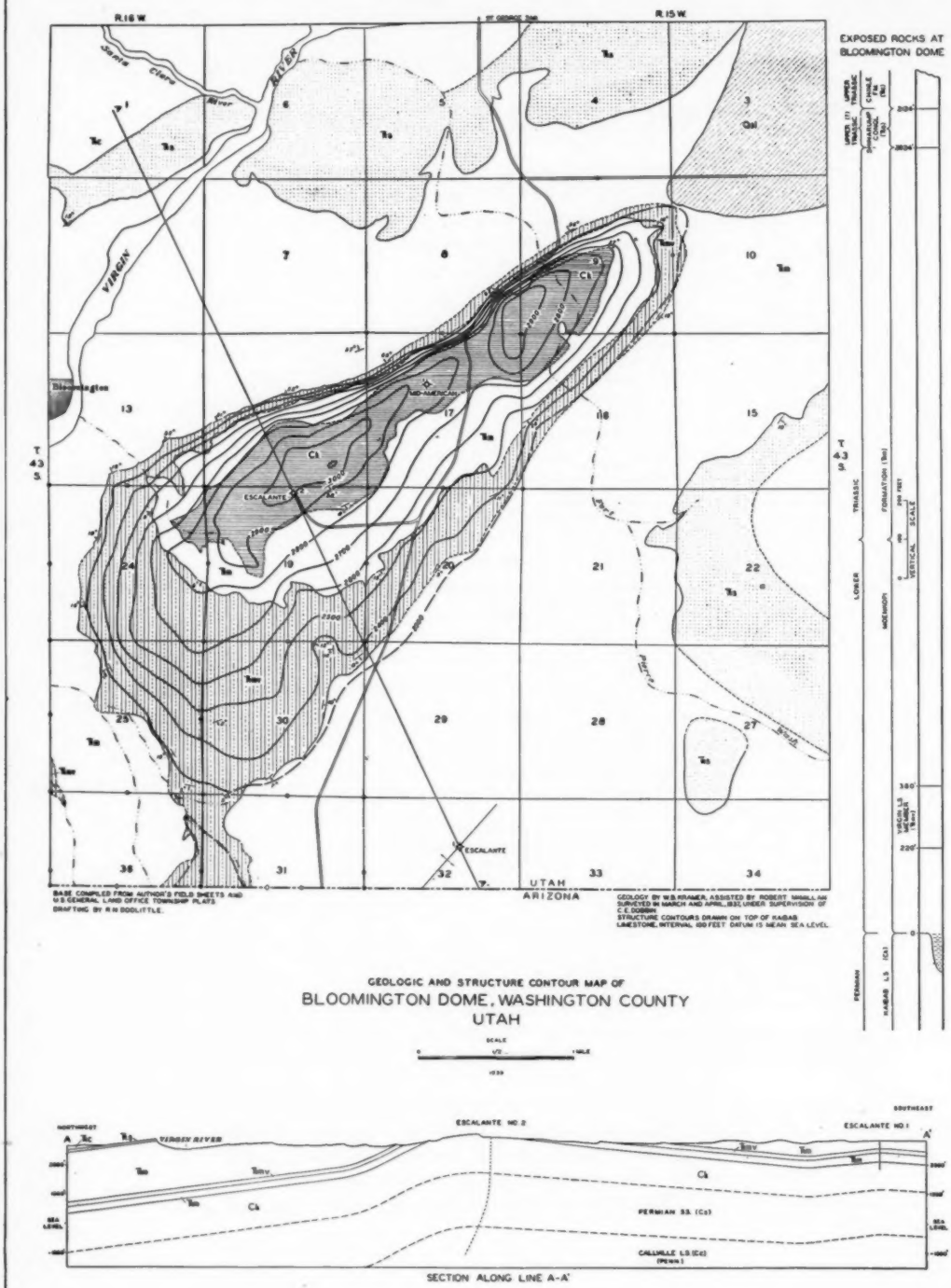

R.16 W.
R.15 W.
Santa Clara River
VIRGIN RIVER
Bloomington
ESCALANTE
MID-AMERICAN
T 43 S.
UTAH
ARIZONA
EXPOSED ROCKS AT BLOOMINGTON DOME
UPPER TRIASSIC
TEMPLE CAP FM. (Tc)
CHINLE FM. (Tch)
TRIASSIC
LOWER
MOENKOPI
FORMATION (Tm)
VERTICAL SCALE
KAIBAB LS. (Pk)
PERMIAN
GEOLOGIC AND STRUCTURE CONTOUR MAP OF
BLOOMINGTON DOME, WASHINGTON COUNTY
UTAH
SCALE
1 MILE
NORTHWEST
SOUTHEAST
VIRGIN RIVER
ESCALANTE NO. 2
ESCALANTE NO. 1
PERMIAN SS. (Cs)
CALLVILLE LS. (Cc)
SEA LEVEL
SECTION ALONG LINE A-A'

FIGURE 11

on March 6, 1935, a premature explosion occurred, killing ten people and wounding others. The well began in gypsum 75 feet below the top of the Kaibab limestone and, according to the drillers' log (page 141), reached the base of the Kaibab at a depth of about 1,227 feet. These figures, however, make the Kaibab 332 feet thicker than the thickest detailed section of it measured at the outcrop in the area.

According to H. F. Davies,[15] who examined the cores from this well, the base of the Permian sandstone underlying the Kaibab was reached at a depth of 3,107 feet, the thickness of the sandstone being 1,880 feet. At a total depth of 4,114 feet the hole is probably bottomed in the lower half of the Callville limestone. It is questionable whether the showings of oil reported in this well were actually found and whether the drillers' log given herein is reliable.

HARRISBURG DOME

The only test of the Virgin anticline northeast of the Washington fault is that by the Virgin Dome Oil Company on the Harrisburg dome, NW. ¼, NW. ¼ of Sec. 16, T. 42 S., R. 14 W. (No. 6, Fig. 2). This well was begun near the top of the Kaibab limestone in 1919 and, after drilling had continued to about 3,400 feet before 1923, the well was shut down. In November, 1929, the company reorganized and resumed operations on the same hole at a depth of 1,820 feet. Late in 1934 the well was shut down indefinitely at a depth of 3,381 feet. Examination of a drillers' log of unknown source and doubtful reliability indicates that the base of the Kaibab was reached at 1,014 feet. Between 1,014 feet and 2,508 feet the log shows mostly sandstone. Below the latter figure to a depth of 3,000 feet, limestone, sandstone, and shale are recorded. Although it can not be proved with available data, it is believed that the bottom of the hole was in the upper part of the Callville limestone. According to Ross Heaton,[16] Harrisburg dome has a closure of 900 feet.

PUNCHBOWL DOME

The small, symmetrical, faulted Punchbowl dome in Sec. 1, T. 43 S., R. 15 W., is outlined at the surface by low, encircling outcrops of the Virgin limestone member of the Moenkopi formation. The drilling of well No. 1 of the Arrowhead Petroleum Corporation was commenced in the SW. ¼, NE. ¼ of Sec. 1, March 25, 1929; drilling was suspended at 860 feet in November, 1929, and resumed November 23, 1930. The well was abandoned at 1,185 feet in November, 1932, because of a crooked hole. Well No.1-A (No.4, Fig. 2) was begun at

[15] Personal communication.

[16] Personal communication.

the same location, November 25, 1932, and on September 31, 1936, was shut down at 2,540 feet. The base of the Kaibab limestone was reached at a depth of 1,260 feet and subjacent sandstone was drilled to total depth. Three showings of oil were reported at and below 2,190 feet. According to Heaton, the dome has a closure of 240 feet.

BEEHIVE DOME

The Beehive dome in Sec. 30, T. 43 S., R. 14 W., is a small fold trending north and south in outcrops of the Shnabkaib shale member of the Moenkopi formation. The west limb of the fold is probably due to drag along the Washington fault. The drilling of the St. George Oil Company well No. 1 (No. 5, Fig. 2), NE. ¼, NW. ¼ of Sec. 30, was commenced December 1, 1927, and ceased at a total depth of 971 feet in December, 1930. The well began near the base of the Shnabkaib shale and ended in the top of the Kaibab limestone.

WHITE DOME

White dome, in fractional Sec. 32, T. 43 S., R. 15 W., is a low northeast-trending anticline in the Moenkopi formation. The drilling of well No.1 (No. 3, Fig. 2) of the Escalante Explorations, Inc., in the NE. ¼ of the section, was commenced, November 23, 1934, and the well was abandoned as a dry hole on March 6, 1935, in the upper part of the Kaibab limestone at a total depth of 969 feet.

OIL AND GAS POSSIBILITIES

The Virgin oil field, 6 miles east-northeast of La Verkin, was discovered in 1907 and has produced a little oil since that date from the basal limestones of the Moenkopi formation, which seemingly dip gently northeast. Stimulated by this discovery, six deep wells have been drilled in the St. George district without finding commercial quantities of oil or gas.

The results of drilling on the Punchbowl, Beehive, and White domes show that the producing zone in the Virgin field does not yield commercial amounts of oil and gas on the most promising folds in the district containing that zone. The tests of Bloomington and Harrisburg domes show that lower beds, down to the lower part of the Callville limestone (Pennsylvanian) do not yield marketable amounts of oil and gas on two of the three most promising domes in the district. It is believed, therefore, that the oil and gas possibilities of the district are not promising.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 145-211, 8 FIGS

STRATIGRAPHY AND HISTORICAL GEOLOGY OF GULF COASTAL PLAIN IN VICINITY OF HARRIS COUNTY, TEXAS[1]

WILLIS G. MEYER[2]
Dallas, Texas

ABSTRACT

A description of all post-Weches formations of the Gulf Coastal Plain in the vicinity of Harris County, Texas, and the geologic history of the Gulf Coastal Plain of southeastern Texas are presented. The many deep wells in this region make it a favored area for such an investigation as the one here attempted. A comparison of surface sections with subsurface sections reveals important changes of facies in nearly every formation.

A geosyncline of major dimensions is located near the outer margin of the Gulf Coastal Plain in eastern Texas and Louisiana. The formation of this geosynclinal depression and the accumulation of sediment in it are the dominant features of the Cenozoic history of this region. Tertiary and Quaternary deposits in the vicinity of Galveston, Texas, are estimated to be 35,000 feet thick. The origin of this geosynclinal depression is discussed.

INTRODUCTION

Since the publication of E. T. Dumble's comprehensive studies of the Tertiary of eastern Texas, a great number of stratigraphic data have been made available by the drilling of thousands of deep oil wells in the region. Although many admirable papers have been written on the Tertiary of the Texas Gulf Coast since the advent of deep drilling in the area, full advantage has rarely been taken of available subsurface data, with the result that the emphasis, in most cases, has been placed upon surface geology.

The purpose of this investigation is to make a detailed study of the subsurface formations of an area in eastern Texas and to continue the investigation up the regional dip to the outcrop of these formations. By thus emphasizing the subsurface development of the formations, it is hoped to bring about a better understanding of the stratigraphy and historical geology of the area than was previously possible.

The writer has relied largely on the work of others for descriptions of the formations at the outcrop though some descriptions are based on his own field work. To a large extent this article complements the surface work of other geologists.

The area described centers in Harris County, Texas. Surface and

[1] Dissertation submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements of the degree of Doctor of Philosophy. Manuscript received, October 15, 1938.

[2] Geologist, E. DeGolyer and L. W. MacNaughton, 611 Continental Building.

FIG. 1.—Index map showing location of area discussed and position of oil fields and oil wells referred to in text.

subsurface studies were extended northward from Harris County to the outcrop of the Cook Mountain formations which are the oldest beds penetrated, at the time of this writing, by wells drilled in Harris County.[3] The investigation was also made southward to the Gulf of Mexico and into neighboring counties on the east and west. It is hoped that a sufficiently large area has been included so that the post-Weches stratigraphy and historical geology of most of southeastern Texas will be apparent. Insofar as time would permit, the results of this investigation have been presented in the framework of a generalized comparison of the formations in the area with those of southwestern Texas and southern Louisiana.

The writer has received the coöperation of many individuals in this undertaking. Officials of the Amerada Petroleum Corporation made available all laboratory facilities of the company, cores and samples of rock-cuttings from many wells, and other geologic data on all wells drilled in this area. Without this coöperation, the completion of the investigation would have been impossible.

The writer is also indebted to W. H. Bucher, N. M. Fenneman, and J. L. Rich, of the University of Cincinnati, for reading the manuscript and offering valuable recommendations. Lewis W. MacNaughton contributed freely from his unpublished surface studies and read and criticized the first draft of the manuscript. G. I. Atwater, Lon D. Cartwright, Jr., A. R. Denison, H. N. Fish, Marcus A. Hanna, and Bruce H. Harlton also read the manuscript and offered many suggestions. Conversations on various phases of the work were also had with J. S. Cruse, Jr. Illustrations were made by E. E. Hurt.

STRATIGRAPHY

GENERAL FEATURES

The Tertiary and Quaternary systems of the Texas Gulf Coast at the outcrop are a succession of marine and continental deposits. As the seas periodically advanced and retreated over the area now occupied by the outcrop of these systems, series of strata were deposited which are alternately marine and continental. The two oldest Tertiary formations and all but the upper part of the next oldest are marine at the outcrop. Succeeding formations as far up the section as the Frio (Oligocene) are alternately marine and continental although the Frio and all younger formations are entirely continental at the surface.

[3] One well was recently drilled in northern Harris County approximately 2,500 feet below the top of the Cook Mountain. The total depth of this well may be in beds as old as the Wilcox. Descriptions of these older deposits are not given here.

In the area adjacent to the present shore line, no continental deposits are encountered below the Middle Miocene while drilling for oil. If a well in this area were to be drilled to the base of the Crockett (upper Claiborne) all beds encountered from the Lower Miocene down would be marine. The beds above the Lower Miocene, except for the upper 200–300 feet, contain shell fragments and may be largely marine although some are probably continental. All formations from the base of the Crockett to the Lower Miocene that are continental at their outcrop grade into a marine facies in the area between the outcrop and the present shore line of the Gulf of Mexico.

Harris County, Texas, is in this intermediate area (Fig. 1). Due to this fact we are concerned, among other things in the stratigraphic part of this investigation: with the determination of valid criteria for distinguishing marine from non-marine deposits in well sections; with the structural, petrographic, and faunal changes that occur in a formation incident to its transition from the continental to the marine facies; with the correlation of formations that undergo such lateral changes; and with the relationship of paleogeography to oil accumulation.

Argillaceous and arenaceous sediments predominate in the Cenozoic deposits of the Texas and Louisiana Gulf Coast. Almost all formations contain these two types of sediments in varying proportions, and this general lithologic similarity among the formations contributes to the difficulty of defining formational limits. The continental facies of some of the formations contains volcanic ash and other pyroclastic material. Pure limestone strata are rare and most of the calcium carbonate is in the form of cementing material in sandstone, as reefs around salt domes, in the form of calcareous nodules, or contained in marls.

Several unconformities are present in the Tertiary section at the outcrop and some probably extend as far gulfward as Harris County. The section must also contain many diastems, as is shown later.

The general classification of the Tertiary and Quaternary deposits in eastern Texas, according to Plummer,[4] is given in Table I. Formations older than the Crockett have not yet been reached by the drill in Harris County,[5] and the classification of the deposits in Harris County used here is not identical with that of Plummer. A table of classification for the deposits in Harris County and vicinity with a résumé of formational properties is given where detailed description of the formations is made.

[4] E. H. Sellards, W. S. Adkins, and F. B. Plummer, "Geology of Texas," Vol. 1, *Univ. of Texas Bull. 3232* (1932), p. 530.

[5] See footnote 3.

A most striking feature of the Cenozoic section here is its great thickness and a characteristic gulfward thickening of most of the constituent formations. An estimate of the thickness of these beds may be obtained by combining the sections from a series of deep

TABLE I

CLASSIFICATION OF STRATIGRAPHIC DIVISIONS IN TEXAS

Age	*Group*		*Formation*	*Members Northeast Texas*
Pleistocene	Houston		Beaumont	Undivided
			Lissie	Undivided
Pliocene	Citronelle		Goliad	Undivided
Pliocene and Miocene	Fleming		Lagarto	Undivided
			Oakville	Undivided
Oligocene?			Catahoula	Onalaska
				Chita
	Gueydan		Subsurface strata	*Discorbis* zone
				Heterostegina zone
				Marginulina zone
Oligocene			Frio	Absent east of Brazos
			Subsurface strata	Undivided
	Jackson		Fayette	Whitsett
				McElroy
				Caddell
	Claiborne		Yegua	Undivided
		Cook Mt.*	Crockett	Undivided
			Sparta	Undivided
		Mt. Selman*	Weches	Undivided
			Queen City	Undivided
			Reklaw	Undivided
Eocene			Carrizo	Undivided
	Wilcox		Sabinetown	Undivided
			Rockdale	Calvert Bluff
				Simsboro
				Butler
			Seguin	Caldwell Knob
				Solomon Creek
	Midway		Wills Point	Kerens
				Wortham
				Mexia
			Kincaid	Pisgah
				Littig

* According to United States Geological Survey usage in 1932.

wells located along a line generally parallel with the regional dip. The well nearest the coast gives the thickness of the younger formations, and those farther inland give successively the thickness of the older formations. The following wells are selected for this purpose and the sectional thicknesses recorded.

	Feet
Shell Petroleum Corporation's Maco Stewart No. 1, southern Galveston County; Recent to top of Frio	10,257
Skelly Oil Company's F. C. Cobb No. B-14, Van Vleck oil field, northern Matagorda County; Frio	4,275
Bunte Oil and Gas Company—Texas Gulf Producing Company's Westmoreland Development Company No. 1, Harris County west of Houston; top of *Textularia warreni* zone to top of Yegua	2,050
Superior Oil Company of California's D. F. Butler No. 1, northern Harris County; top of Yegua to top of Wilcox	3,513
Hall-Edwards *et al.* Francis Fulcher No. 1, east-central Madison County; top of Wilcox to lower part of Midway	3,964
Total thickness of Cenozoic more than	24,059

As thus indicated, the figure for the total thickness of the Cenozoic formations represents only a first approximation obtained by projecting shoreward the thicknesses of the lower formations measured at points farther inland. It is not probable that the formations retain their thicknesses over the distances involved. Two other possibilities exist. One is that during any particular cycle of sedimentation, the supply of sediment may not have been sufficient to build the wedge-shaped formation out as far as the present shore line, or that the cycle may have been interrupted before this could be accomplished. The other possibility is a continued gulfward thickening of the formations. As deeper drilling continues in the Gulf Coast, it is becoming more and more certain that thickening continues at least as far as the present shore line. If one assumes a continuation of formational thickening instead of a maintenance of the actual thicknesses recorded at points inland, a much greater figure for the estimated thickness of the Cenozoic is obtained. The following thicknesses of the Cenozoic formations are estimated by projecting shoreward rates of thickening observed in areas farther inland.

	Feet
Recent to marine Lower Miocene (inclusive)	11,000
Frio	5,200
Textularia warreni beds	1,490
Jackson	2,500
Yegua	1,850
Crockett-Carrizo (inclusive)	2,760
Wilcox-Midway	11,600
	36,400

It is altogether possible that even this estimate is less than the real thickness of these deposits. All evidence available shows not only that formational thickening continues but also that the rate of thickening itself increases with proximity to the present shore line. For example, if the thickness of the deposits from the Recent to the top of the Frio in southern Galveston County were estimated by projecting the amount of thickening involved between Tomball wells and the Westmoreland well in southern Harris County, a figure of

7,400 feet would be obtained. Where the Shell Petroleum Corporation's Maco Stewart No. 1 was drilled in southern Galveston County, however, these deposits were found to be 10,257 feet thick. Thus the estimated thickness is only 72 per cent of the true thickness of these formations. The area occupied by the counties adjacent to the coast has been depressed much more than the area farther inland. In view of this fact, it would not be unexpected to find that the Cenozoic deposits along the coast south of Houston, Texas, reach a thickness greatly in excess of 35,000 feet.

Although it is probable that these deposits do reach a thickness of 35,000 feet, the fact remains that formational thickening as far south as the present shore line has not yet been proved for formations older than the Frio. However, formational thickening to a point 15 miles north of Houston for deposits of Cook Mountain age has been proved.

It is interesting to note that Howe[6] has arrived at a similar estimate for the thickness of the Cenozoic in southern Louisiana. He and his colleagues estimate that the base of the Tertiary in southeast Vermilion Parish is at a depth of 31,250 feet. Although the post-Oligocene deposits there are thicker than they are in southern Galveston and Matagorda counties, Texas, the total thickness of the Cenozoic in the former area is probably not greater than in the latter.

CRITERIA FOR DISTINGUISHING MARINE FROM NON-MARINE DEPOSITS

Before presentation of a detailed description of the Cenozoic formations and an interpretation of the facts of stratigraphy as represented by the core records, Schlumberger logs, and other data, the criteria here relied on to distinguish a marine facies from a non-marine facies are summarized.

Some of the criteria that are useful when studying surface exposures are not available to the subsurface geologist. Such features as rain-drop impressions and mud cracks are obliterated by the drill and megascopic fossils are ordinarily broken beyond recognition.

The presence of marine fossils generally implies marine deposition. Echinoid fragments are valid evidence for marine conditions of accumulation, but they do not occur with sufficient abundance throughout the Texas Gulf Coast Tertiary and Quaternary to be of more than occasional assistance. All but an insignificant number of ostracods are restricted to marine or brackish waters. As fresh-water ostracods

[6] Henry V. Howe, Richard J. Russell, and James H. McGuirt, "Geology of Cameron and Vermilion Parishes," *Louisiana Geol. Survey Bull. 6* (1935), p. 41.

do not appear to be present in the beds in this area, the presence of ostracods may be taken as indicating marine deposition. They are not found in great abundance, however, and their value is correspondingly limited. Fragments of pelecypods and gastropods occur abundantly in parts of this section, but although they are generally marine, some may be fresh-water forms, and they should not be used unless their identity can be established. For some forms this is not possible. The only fossils which are small enough to escape destruction during drilling operations and yet occur in sufficient abundance to be generally useful are the Foraminifera. Although this group is not exclusively marine, it is nearly so, and the fresh-water forms seem either not to have existed here during Cenozoic time or not to have been preserved. Even errors due to the possible existence of non-marine forms can be eliminated because the Foraminifera ordinarily are sufficiently well preserved to permit identification.

Care must be exercised, however, that only fossils indigenous to the formations are used. Marine fossils can be, and have been, eroded out of Cretaceous and older beds and redeposited in non-marine Cenozoic strata. Furthermore, small marine fossils may occur far inland in terrestrial dunes, having been transported when the winds were from the sea. No exact rule can be formulated to guard against such a contingency. Only the general aspect of the fossil will give evidence of possible redeposition by wind or water. Fossils bearing evidence of redeposition can not be used as a criterion for determining the conditions of deposition of the beds in which they are found.

The presence of indigenous glauconite in a bed also indicates marine deposition. Galliher[7] in his work on glauconite states that its diagenesis from biotite occurs exclusively in a marine environment. Although glauconite is thus a useful index mineral for marine beds, the difficulty of distinguishing indigenous glauconite from reworked glauconite detracts from its usefulness. There is, seemingly, no good way of distinguishing these two types. For the purposes of this investigation then, the presence of glauconite in a bed is not taken as conclusive evidence of marine origin of that bed but is considered as strong supporting evidence when other characteristics suggest marine origin.

Although glauconite and marine fossils are the only indices of a petrographic and paleontologic nature for marine beds, one other type of criterion is available. This type is structural, and only one such criterion seems to be applicable to subsurface work. Large areal

[7] E. Wayne Galliher, "Geology of Glauconite," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 11 (1935), pp. 1569-1601.

distribution and relatively uniform thickness of thin sands are found only in marine beds in the Gulf Coast Cenozoic deposits. The transition from highly lenticular sands in the non-marine facies of a formation to "blanket sands," as the more continuous beds are called, in the marine facies is an almost universal characteristic of the Cenozoic deposits of this area. The areal extent of the non-marine lenses is measured in hundreds or thousands of feet, and the extent of the marine blanket sands is measured in miles or tens of miles. There is generally no mistaking these types of sand bodies.

To prove that sediments are non-marine is ordinarily more difficult than the converse because they rarely contain fossils of any kind and because the absence of a marine fauna can not be taken to imply a non-marine facies. It is true that leaf imprints and pieces of silicified wood are found in some cores, but these can be and in some places are washed out to sea some distance from the shore and become deposited in marine sediments.

There is likewise little evidence to be derived from the petrography of the sedimentary rocks because the source generally is the same for all facies of any particular formation. There is one lithologic character, however, which seems to furnish a valid criterion for this particular area. At the outcrop of the Yegua where tree stumps *in situ* establish its terrestrial character, there are many beds of unaltered ash, ashy sandstone, and ashy shale. This is not true of the formation a considerable distance down the regional dip where there is an abundance of marine fossils, although it does contain, as an equivalent, thin beds of bentonite and bentonitic shale. Thus a section barren of marine fossils but containing many ash beds may be considered non-marine.

Just as blanket sands suggest marine deposition so highly lenticular sand bodies point toward non-marine deposition. Where many wells have been drilled, and Schlumberger logs are available, any lenticularity of the sands may be readily detected and non-marine deposition is implied.

Of the several criteria given, none can be said to supply positive proof of the mode of origin of the beds which they characterize. It has been noted that marine fossils and glauconite can be found in non-marine beds. Likewise ash beds and sand lenses can be found in marine deposits. Yet a strong case is established for the mode of origin of nearly every formation, because in nearly every instance where one of the criteria is present one or more other criteria, indicating the same mode of origin, are present also. Each case rests on two or more convergent lines of evidence. But what is most important is that in

TABLE II

TABLE OF FORMATIONS PENETRATED BY THE DRILL IN HARRIS COUNTY AND VICINITY

Age	*Group*	*Formation*	*Member*	*Thickness in Feet at Outcrop in Eastern Texas*	*Thickness in Feet in Harris County*	*Thickness in Feet at Shore Line South of Harris County*	*Facies at Outcrop*	*Facies in Harris County*
Pleistocene	Houston	Beaumont	Undivided	1,000–1,500	1,200	2,160	Non-marine	Outcrops in Harris Co.
		Lissie	Undivided				Non-marine	Outcrops in Harris Co.
Pliocene		Willis	Undivided	80–85			Non-marine	Outcrops in Harris Co.
Pliocene-Miocene	Fleming	Lagarto	Undivided	1,300–1,450	1,300–2,225	4,000	Non-marine	Non-marine
		Oakville	Undivided					
Miocene		Catahoula	Undivided	300–600	600	700	Non-marine	Non-marine
		Marine Lower Miocene	*Discorbis* zone *Heterostegina* zone *Marginulina* zone	0	400–850	3,400	Absent	Marine
Oligocene		Frio	Undivided	Overlapped	1,300–1,900	Not penetrated in normal well sections	Overlapped	Non-marine and marine
		Textularia warreni beds	Undivided	0	300–670		Absent	Marine
Eocene	Jackson	Fayette	Whitsett McElroy Caddell	900	1,075–1,380		Non-marine and marine	Marine
	Claiborne	Yegua	Undivided	750–1,000	1,430		Non-marine	Marine
		Crockett-Sparta (Cook Mountain)	Undivided	425	1,465		Non-marine and marine	Marine

formations where evidence of both marine and non-marine deposition is present, the features which indicate non-marine deposition are found landward from the area where marine characteristics are prevalent in the formation. This presents a rational picture of the formation and is consistent with the Cenozoic history of the area as all marine invasions came from the south.

EOCENE SERIES

CLAIBORNE GROUP

CROCKETT FORMATION

The oldest formation penetrated by wells drilled for oil in Harris County, Texas, is the Crockett.[8] The lower limit of this formation at the outcrop is the contact between the underlying non-fossiliferous, continental sands of the Sparta formation and the overlying fossiliferous, marine shales, sandy shales, and sands. The upper limit is the highest occurrence of *Ceratobulimina eximia* (Rzehak).

Little is known of the Crockett formation in Harris County as only a few wells ever reached beds of this age, and only data of a general nature are available on the Crockett of those well sections. However, many wells have been drilled through the Crockett up the regional dip from Harris County, and generalizations can be made about the strata of this age in the eastern part of the Texas Gulf Coast, and some inferences can be made about them in Harris County.

Plummer[9] reports the presence of a disconformity at the Sparta-Crockett contact in the outcrop. There are no subsurface data to indicate the nature of the basal contact in the vicinity of Harris County.

Distribution and thickness.—Strata containing a Crockett fauna have been reported in well sections from Webb County in southwestern Texas northeastward across the state to the Sabine River. The formation is at the surface in the eastern and central part of the Texas Coastal Plain. In the lower Rio Grande region, Trowbridge[10] describes the upper part of the Cook Mountain as being more shaly than the rest and having a distinctive fauna. As this immediately underlies the Yegua, it is probably the equivalent of the Crockett formation in eastern Texas. Crockett strata were also encountered in the Amerada Petroleum Corporation's Weil well No. 1 in the Cheney-

[8] See footnote 3.

[9] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 652.

[10] A. C. Trowbridge, "Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," *U. S. Geol. Survey Bull. 837* (1932), pp. 121–24.

ville oil field in Rapides Parish, Louisiana, and equivalent beds have been reported at the surface in Louisiana.

The Crockett is 125 feet thick at the outcrop in the Brazos River valley of Robertson County according to Renick and Stenzel. It is 400–450 feet thick in well sections in Houston County, nearly 500 feet thick in Walker County, and 550 feet thick in Grimes County. The Magnolia Petroleum Company's William Martens well No. 1, in northern Harris County, was drilled approximately 750 feet into the Crockett without any indication of having reached Sparta beds, and The Superior Oil Company of California's Butler well No. 1, in north-central Harris County, encountered 1,465 feet of Crockett strata. In the Cheneyville oil field in Louisiana it is 539 feet thick.

Lithologic character.—Data from well sections indicate that the Crockett is largely shale with a minor amount of sandy shale. The shale varies in color from gray to chocolate-brown, is fossiliferous and, in places, glauconitic. All beds have parallel lamination.

Plummer[11] describes the formation at the surface as consisting

> of about 90 per cent fine sediments, clay, shale, and sandy shale, 9 per cent medium-grained sediments, sand and glauconite, and 1 per cent rock, limestone and ferruginous concretions.

Conditions of accumulation.—The Crockett in well sections contains marine fossils and glauconite. Although the Crockett in the vicinity of Harris County is nearly devoid of sands and the criterion of the continuity of thin sands can not be applied, the faunal evidence leaves little doubt as to the marine origin of this formation. Most of it at the surface is likewise marine. The lower and middle parts at the surface are entirely marine and the upper part contains both marine and non-marine sediments deposited, apparently, near the shore line.

Paleogeography.—The shore line during lower and middle Crockett time was an unknown distance inland from the site of the present outcrop, and during upper Crockett time, the seas retreated to a position a short distance south of the outcrop, leaving the area now occupied by Harris County a considerable distance seaward from the shore line all during that period.

YEGUA FORMATION

Overlying the Crockett beds is the Yegua formation. Two wells in the Tomball oil field have been drilled through the Yegua, and another, the Amerada-Stanolind's John Bode well No. 1, in the same area, penetrated 1,138 feet below the top of the Yegua but did not

[11] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 660.

reach the Crockett. The Amerada-Stanolind's Louis Dopslauf well No. 1 at Fairbanks was drilled 970 feet into the Yegua. The latter two wells were extensively cored in the Yegua and furnish much information about this formation. Another well, 3 miles west of the Harris County-Waller County line, was drilled into the top of the Crockett, and its records are extensive and available. In addition to these wells which were drilled through or nearly through the Yegua, there are many which have been drilled 300–500 feet into this formation giving many data on this part of the section.

At the outcrop the Yegua lies unconformably on the Crockett formation. It is not definitely known whether or not this unconformity extends as far south as Harris County.

Distribution and thickness.—The Yegua underlies all parts of Harris County except the places where it is pierced by salt plugs. This is likewise true of all the rest of the Texas and Louisiana Gulf Coast south of the outcrop.

The Superior Oil Company of California's Butler well No. 1 in northern Harris County went through 1,434 feet of Yegua beds. A greater thickness must be given to the formation in southern Harris County. In northern Montgomery County it is 1,242 feet thick and at the outcrop it is about 1,000 feet thick.

Lithologic character and structures.—Cores, rock-cuttings, and Schlumberger logs from many wells show that sand, sandstone, sandy and silty shale, and shale make up the entire Yegua with the exception of several very thin beds of bentonite and one thin bed of lignite which occur only in the north part of the county. At Tomball, sand and sandstone beds varying in thickness from 1 foot to 50 feet make up 40 per cent of the Yegua, although at Fairbanks they comprise 20 per cent of the formation.

The sands and sandstones are almost entirely quartzose. Plummer[12] estimates that the continental sandstones at the outcrop are more than 99 per cent quartz. This is probably true of the marine sandstone in Harris County also. The grains are subround, generally clear, but some are milky and a very few are grayish blue. Very rarely chert grains are present, and many of the sandstone beds contain muscovite and fragmental lignite.

The shale is characterized by a chocolate-brown or greenish brown color, is brittle, and has a conchoidal fracture. The chocolate-brown color is particularly characteristic of the upper part of the formation and contrasts rather sharply with the gray shales of the overlying

[12] E. H. Sellards, W. S. Adkins, and F. B. Plummer, "Geology of Texas," *Univ. Texas Bull. 3232* (1932), p. 672.

Caddell formation. Nearly all the Yegua shales contain small fragments of lignite and are micaceous, biotite being particularly conspicuous. Many of the beds are also glauconitic and pyritic and some fossils and lignitic fragments have become pyritized.

In the vicinity of Tomball a 6-inch bed of light green bentonite is present at the top of the formation and another bed of very light-colored bentonite occurs just above the second sandstone about 275 or 300 feet below the Yegua-Jackson contact. In the same area a 6-inch lignite bed is found in the middle of the first sandstone.

The distribution of the sandstone and shale beds is not uniform throughout this part of the section. The upper 220–240 feet are shale with some thin streaks of sandy or silty shale. Below this, sandstone beds ranging from a few inches to 50 feet thick are interstratified with the shale, making a very distinct lithologic break. That this sandstone and shale series continues down as far as the top of the Crockett is shown by the Schlumberger log and the cores from the Stanolind *et al.* J.W. Thorpe well No. 1 in Waller County which was drilled completely through the Yegua formation.

Generally the sandstone beds are of the blanket type and do not lense out and interfinger as they do at the outcrop. The upper five sandstone strata have been drilled or cored in many places in the quest for oil. All of these can be traced as far as 20 miles down the regional dip from Tomball and for considerable distances along the strike.

Many of the thinner sandstone strata are cross-bedded. As cores give a very small sample of the formation, a detailed study of the cross-bedding is not possible. It is important to note, however, that this structure may be encountered anywhere in the sandy part of the formation and is not restricted to a particular zone.

Conditions of accumulation.—The presence of marine foraminifers, marine ostracods, and pelecypod and gastropod fragments together with much glauconite establishes the marine character of the Yegua in Harris County. This is corroborated by the continuity of the blanket sands which are in striking contrast to the lenticular, interfingering sands of the continental facies at the outcrop.

Paleogeography.—Although the approximate position of the shore line of the Yegua sea can be determined from a study of the sections from wells drilled north of Harris County, the exact position can not be established because of the relatively few wells that have been drilled into the Yegua formation in this area.

The Shell Petroleum Corporation's H. M. Creighton well No. 1 in central Montgomery County was drilled 518 feet into the Yegua.

This is completely marine. Although fossils are very common in the upper 220 feet they are very rare below this point. It is this point too that marks the break between the upper shale zone and the lower zone of sandstone and shale. This suggests that the shore line was a relatively short distance north of this well while all excepting the upper 220 feet of the sediments were being deposited. It is probable that during early Yegua time the shore was a very short distance south of the site of the middle Yegua shore line as Foraminifera are a little more rare in the lower Yegua than in the middle Yegua at Tomball. Near the close of the epoch, the shore line moved northward into Walker County and remained there while the 230 feet of shale in the upper part of the formation were being deposited in the area now covered by Harris County.

These positions for the lower, middle, and upper Yegua shore lines are substantiated by evidence from Chapman and Smith's Delta Land and Timber Company well No. 1 in northern Montgomery County. Although cores were taken in this well only in the upper 670 feet of the Yegua, it was drilled into the Crockett and the rock cuttings from the whole formation have been examined. In a core 232 feet below the top of the formation an ashy, slightly sandy shale bed was found. Below this bed are several similar ashy strata. One bed of ash more than 10 feet thick was encountered a little less than 1,000 feet below the top.

In the upper part of this ashy series are several sandy shale beds that contain *Ammobaculites* sp. Special significance is attached to this genus. Of it Cushman[13] states,

> There is a wide range of habitat in the present ocean, some species only found in cold, deep water, others in very shallow warm waters of the tropics.

Although it is found here in many places in the Tertiary associated with other marine Foraminifera, in some places it occurs alone in sandy beds situated in localities farther north (shoreward) than the areas where other genera are found. It seems to have been able to survive in shallower water and nearer shore than other forms. Its presence in these sandy beds where other marine fossils are absent is considered indicative of the proximity of the shore line. Above the first ashy bed in this well is an abundance of marine fossils.

Aside from minor fluctuations, these facts indicate that during lower Yegua time the shore line was in the vicinity of the Shell Petroleum Corporation's H. M. Creighton well No. 1 that during,

[13] J. A. Cushman, "Foraminifera: Their Classification and Economic Use," *Cushman Lab. Foram. Res. Spec. Pub.* 1 (1928), p. 108.

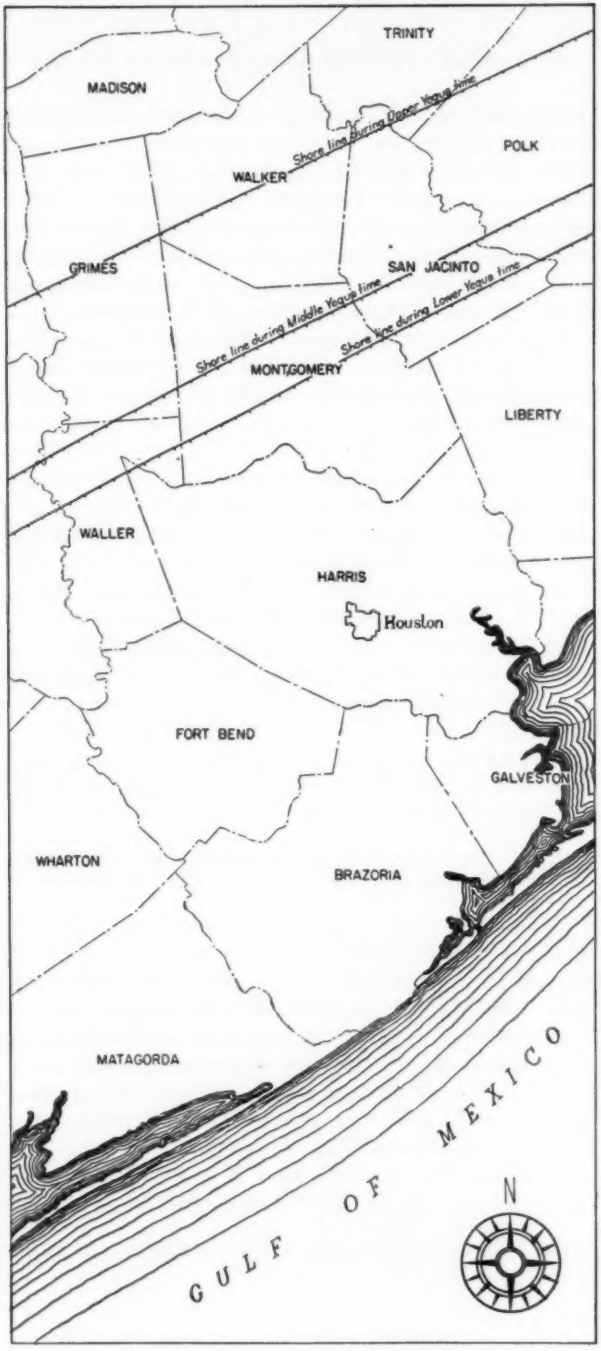


FIG. 2.—Paleogeographic map for Yegua time.

middle Yegua time it migrated a short distance northward somewhere between the latter well and Chapman and Smith's Delta Land and Timber Company well No. 1 and that during upper Yegua time when the upper 230 feet of shale were being laid down in Harris County the shore line stood somewhere in Walker County (Fig. 2). It should be noted that the greatest movement of the shore line came after the lower 1,100 feet of sand and shale had been deposited and before the upper 230 feet of shale were laid down. The difference in the position of the lower and middle Yegua shore lines was not great. The only reason for assuming any difference at all is the greater scarcity of fossils, aside from *Ammobaculites* sp., in the lower Yegua than in the middle Yegua at Tomball.

JACKSON GROUP

FAYETTE FORMATION

Immediately overlying the Yegua beds in the Texas Gulf Coast is the Fayette, the only formation in the Jackson group of Texas. The Jackson group rests conformably on the Yegua both at the outcrop and in well sections throughout Texas.

SUBDIVISIONS

A division of the Fayette of Texas into three members has come into general recognition. In ascending order these are the Caddell, the McElroy, and the Whitsett. Some writers have subdivided each of these at the outcrop on a lithologic basis into several thinner zones.

Although these names for the three members of the Fayette are in general use, there is no unanimity in defining their limits. Three of the most recent writers on the Jackson, Ellisor,[14] Plummer,[15] and Renick,[16] have defined the members on a basis of lithologic properties shown at the outcrop.

The contacts thus described at the outcrop can not be found in well sections because the Fayette, with the exception of the *Massilina pratti* zone, grades into a shale facies within a short distance gulfward in the eastern half of the Texas Gulf Coast. The Fayette from Goliad County southward contains some sand bodies, but even there the contacts between the members as described by these writers probably can not be recognized.

[14] Alva Christine Ellisor, "Jackson Group of Formations in Texas with Notes on Frio and Vicksburg," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 11 (1933), pp. 1293–1350.

[15] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, pp. 677–99.

[16] B. Coleman Renick, "The Jackson Group and the Catahoula and Oakville Formations in a Part of the Texas Gulf Coastal Plain," *Univ. Texas Bull. 3619* (1936), pp. 13–55.

The purpose here is to redefine the several members as much as possible on the basis of properties that are common to the beds both at the outcrop and in well sections south of the outcrop. Obviously a lithologic basis does not meet this requirement. The faunas of these Fayette beds provide the only basis for dividing the formation into members that can be recognized in wide areas. Two major fossil zones can be recognized in well sections from the Rio Grande to the Sabine River and everywhere at the outcrop except in the southwestern part of the state. There the Fayette is more or less unfossiliferous, and largely non-marine. These zones are the *Textularia dibollensis* and the *Textularia hockleyensis* zones. The definitions of the members thus developed divide the Fayette much as it has been divided at the outcrop by recent writers, but they are applicable in larger areas. Finally, they define the members as they are recognized by a majority of oil-company stratigraphers working in the Gulf Coast.

CADDELL

The lower limit of the Caddell is the top of the Yegua, and the upper limit is the top of the *Textularia dibollensis* zone. Because of the abundance of *Textularia dibollensis* Cushman and Applin, which is the key fossil for this member, it is in many places known as the "*Textularia dibollensis* zone."

The Caddell is very fossiliferous both at the outcrop and in well sections. Gastropods, pelecypods, and foraminifers are especially plentiful, and echinoid plates, ostracods, pyritized diatoms, and some fish teeth may be found at certain places. A detailed study of the Caddell faunas would doubtless reveal several distinct fossil zones which would be useful stratigraphic markers. One such zone at the base of the Caddell, the Moody's Branch, is widely recognized. It contains *Camerina moodybranchensis* Gravell and Hanna and *Operculina vaughani* Cushman. This zone can be traced from Texas eastward across Louisiana and Mississippi into Alabama.

McELROY

The McElroy extends from the top of the Caddell to the top of the *Textularia hockleyensis* zone. *Textularia hockleyensis* Cushman and Applin is the index fossil for this member.

Plummer[17] places the top of the McElroy "at the base of the persistent sandstone locally known as Grovetown or 'quarry' sandstone which caps the top of the Lipan Hills." The Grovetown overlies the Falls City shales which contain *Textularia hockleyensis*. Plummer

[17] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 687.

actually divides the Fayette as it is done here, but his definitions can not be applied to the formation as it is encountered in well sections.

Like the Caddell, the McElroy is very fossiliferous in well sections. Pelecypods, gastropods, and foraminifers are especially plentiful. At the outcrop, the middle part is mostly non-fossiliferous and the rest of the McElroy is not as fossiliferous there as it is a short distance gulfward.

WHITSETT

The Whitsett includes all beds between the top of the McElroy and the top of the *Trochammina teasi* zone. At the outcrop it is in contact with the ashy Catahoula formation in the eastern end of the state and with the Frio formation in the southwestern part of the state. In well sections a wedge of marine Vicksburg sediment overlies the Whitsett.

The Whitsett is very fossiliferous where it is encountered in wells drilled south of the outcrop. Foraminifers, pelecypods, and gastropods are most plentiful. It is less fossiliferous at the outcrop, but such faunas as it contains distinguish it clearly from the overlying unfossiliferous, ashy Catahoula and Frio formations.

About 70 feet below the top of the Whitsett in well sections *Marginulina cocoaensis* Cushman is found. Being easily recognized and occurring at a somewhat constant interval below the top of the Jackson, it is a good marker for correlating well sections. The lowest part of the Whitsett is known as the *Massilina pratti* zone. The key fossil for this zone is *Massilina pratti* Cushman and Ellisor. The zone is generally 80–100 feet thick, is easily recognized both in well sections and at the outcrop in the eastern part of the state, but is poorly developed in southwestern Texas.

Distribution and thickness.—The Jackson is present in all parts of the Texas-Louisiana Gulf Coast south of the outcrop except in those places where it is pierced by salt domes. Wherever the Jackson is present in Texas, it is represented by all three members except at the outcrop in the vicinity of Gonzales County where the Whitsett is overlapped.

In the wells drilled a few miles south of the outcrop in Polk, San Jacinto, Walker, Montgomery, and Grimes counties, Texas, the Jackson varies in thickness from 900 to 1,000 feet. In the northern part of Harris County it is approximately 1,075 feet thick. The formational thickening of the Jackson between these two localities is scarcely more than 10 per cent. In northern Harris County the average thickness of the Caddell is 245 feet, the McElroy 580–600 feet, and

the Whitsett 230 feet. In the Bunte-Texas Gulf Producing Company's Westmoreland Development Company well No. 1, 6 miles southwest of Houston, the total thickness of the Jackson is 1,380 feet. It is interesting to note that the most thickening occurred in the Caddell which is 505 feet thick here. The Caddell has twice the thickness in this area that it has at Fairbanks just 12 miles northward. The McElroy in the same well is 640 feet thick and the Whitsett is the normal 230 feet in thickness. In the Stanolind Oil and Gas Company's Angelo Candelari well No. 1 which is 4 miles east of Houston and is 500 feet higher structurally than the Westmoreland Development Company well, the total thickness of the Jackson is 1,243 feet. Here also, the Caddell shows the largest amount of thickening, its thickness being approximately 400 feet. The data from these wells and others strongly indicate a considerable amount of formational thickening of the Jackson. It is very significant that the rate of thickening is much greater south of Fairbanks and vicinity than it is north of there. If one assumes a continuation of the same degree of thickening as is shown between Fairbanks and the Westmoreland Development Company well, the Jackson must be 2,500 feet thick at the present shore line.

Lithologic character.—The subsurface Jackson in the eastern half of the Texas Coastal Plain is made up entirely of shale except for the relatively thin *Massilina pratti* zone which in its typical development is sand and sandy shale.[18] South of Goliad County, the Jackson contains well developed sand bodies and is petroliferous. At the outcrop, the Jackson is lithologically unlike the Jackson below the surface. Plummer[19] estimates that it consists of about 40 per cent sand, 40 per cent sandy or ashy clay, 10 per cent clay, 5 per cent bentonite or fuller's earth, 4 per cent quartzite, and 1 per cent lignite.

The shale is bluish gray to greenish gray in color and contains a very small amount of very minute flakes of mica. In some places, shale beds chocolate-brown in color are encountered in the Caddell. This lowest member is also glauconitic and locally contains bentonitic beds. The Moody's Branch zone is especially glauconitic and is slightly marly.

Conditions of accumulation.—The presence in well sections of foraminifers, echinoid plates, and other marine fossils together with glauconite shows that the Caddell was deposited under marine conditions over the area beginning a short distance south of the outcrop.

[18] An exception to this is a sandy zone in the Whitsett in the Raccoon Bend oil field. This is a local condition, however, and is confined to the area of the structure.

[19] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 690.

It is also marine at the outcrop in the eastern part of the state, and *Textularia dibollensis* has been found at the surface as far west as Cheepside, Gonzales County. The surface studies of Renick,[20] however, show that westward from Trinity County fluviatile and palustrine deposits are interstratified with marine beds.

The entire McElroy is also marine in well sections a short distance south of the outcrop. Marine fossils are plentiful. It is partly marine and partly non-marine at the outcrop. Renick[21] believes that these strata were deposited "under palustrine, fluviatile, lagoonal and littoral conditions." The Dilworth sand and Falls City shales, the upper part of the McElroy, are marine, probably near-shore deposits.

The Whitsett below the surface is marine in all parts of the Texas Coastal Plain, but at the surface in eastern Texas both marine and non-marine deposits are present. Fluviatile and strand-line deposits are interstratified with shallow-water beds.

Paleogeography.—The general advance of the seas which occurred during Yegua time continued during the Jackson. A maximum for this invasion in eastern Texas occurred during Caddell time where the shore line was an unknown but probably not great distance north of the present outcrop. West of Trinity County, however, the strand line was approximately at the position of the present outcrop. A slight retreat of the sea took place during middle McElroy time. Then the strand line was approximately 5 miles south of its former position. The sea readvanced in late McElroy time to a position a very short distance north of the present outcrop where, with the exception of minor retreats, it remained until the close of the Jackson epoch (Fig. 3).

OLIGOCENE SERIES

TEXTULARIA WARRENI BEDS (VICKSBURG IN PART)

A wedge of marine shales and sands overlies the Jackson group in well sections in Texas. The upper part of this marine wedge contains few, if any, diagnostic fossils. *Textularia warreni* Cushman and Ellisor and shell fragments comprise the greater part of the fauna. The first diagnostic fossils are generally found approximately 200 feet below the top of the *Textularia warreni* zone. Ellisor[22] has identified this fauna as Vicksburg in age. Out of sixty species identified, fifty-seven were found in the Vicksburg strata of Mississippi. Although the Vicks-

[20] B. Coleman Renick, *op. cit.*, p. 23.

[21] *Ibid.*, p. 42.

[22] Alva Christine Ellisor, *op. cit.*, pp. 1293–1350.

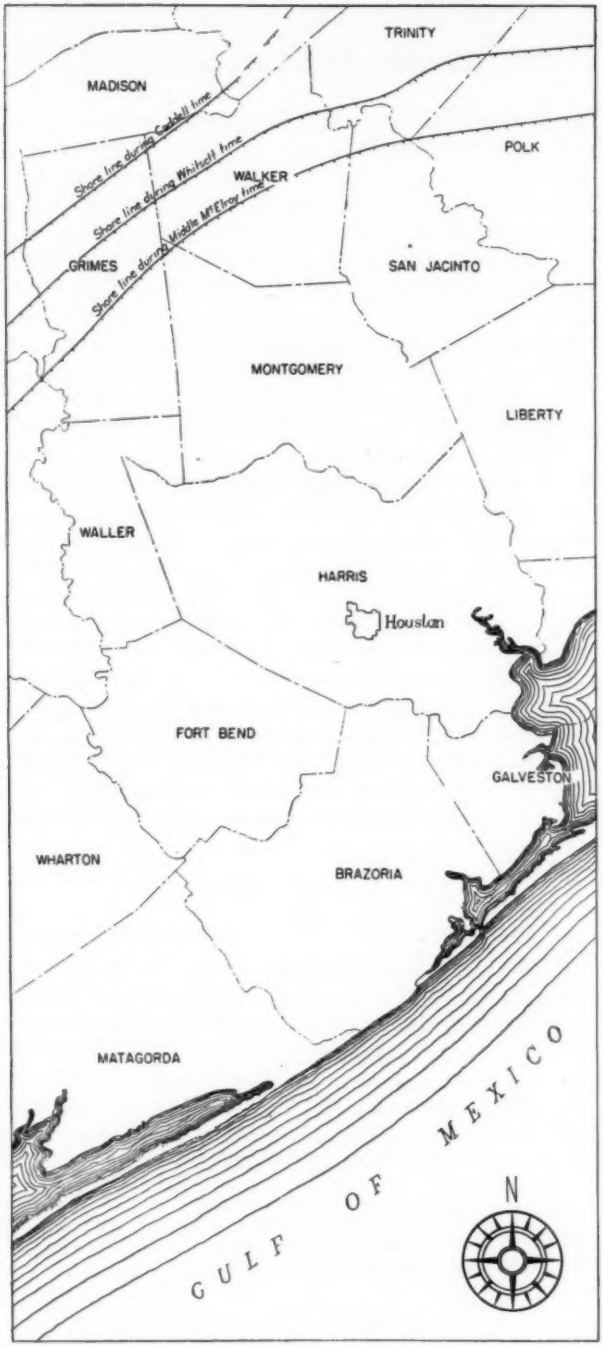


FIG. 3.—Paleogeographic map for Jackson time.

burg age of the lower part of these beds is unquestioned, the equivalent, in the Mississippi section, of the upper part has not been determined. The true Vicksburg part of this marine wedge and the upper part which contains no diagnostic faunas are treated together here as a unit because the deposition of the entire wedge marked a single event in the geologic history of the Texas Gulf Coast, namely, the retreat of the seas at the close of Jackson time from a position far inland to a position near the present shore line. The whole marine wedge thus forms a natural stratigraphic unit. Whether unfavorable environmental conditions account for the absence of typical Vicksburg fossils in the upper *Textularia warreni* beds or whether these upper beds are really younger than the youngest Vicksburg strata in Mississippi is yet to be determined.

Schlumberger logs and rock-cuttings show no pronounced textural change in the formations at the Jackson-Vicksburg contact. *Textularia warreni* beds have never been found to crop out in Texas so that the nature of the basal contact has not been observed directly. In view of the fact that these beds were deposited, as is shown later, as the seas moved gulfward from the inland position which they occupied at the close of Jackson time, continuous deposition and conformable basal contact are to be inferred.

Distribution and thickness.—As stated previously, *Textularia warreni* beds have never been found to crop out in Texas, but they have been reported at the surface in La Salle Parish, Louisiana.[23] The Jackson has been found without exception to be overlain by the Catahoula or Frio formations in Texas.

Fossils of the *Textularia warreni* zone have been found in The California Company's Garcia well No. 1 in Brooks County, Texas, and in the Tidewater-Darby Oil Company's Southwestern Lumber Company well No. 1 in Jasper County, Texas, and in many wells between these two counties. That a continuous wedge of *Textularia warreni* beds extends from the Rio Grande to the Sabine River is a certainty. A projection toward the outcrop of observed rates of thinning between wells in Jasper and Newton counties indicates that the inner limit of this body of sediments is within 5 miles of the outcrop of the Jackson-Catahoula contact.[24] Westward from here in Live Oak County, 120 feet of Vicksburg strata were reported in a well 15 miles

[23] H. N. Fisk, personal communication.

[24] L. W. MacNaughton has pointed out to the writer that the outcropping beds mapped as Jackson in Trinity, Polk, and Angelina counties occupy a wider belt than is normal for the Jackson of Texas. The upper part of these beds is non-marine, contains no diagnostic fossils, and may be equivalent to the *Textularia warreni* beds.

from the outcrop of the Frio-Jackson contact. Exact data of similar nature for the area southwest of Live Oak County are not available to the writer. Reason to believe that these beds do not extend as near the outcrop there as in eastern Texas, however, is found in the fact that the Jackson in southwestern Texas is probably non-marine, and as the Vicksburg records a yet greater retreat of the sea than the Jackson, the assumption is that the Vicksburg must be farther from the Jackson outcrop there where the upper Jackson at the outcrop is non-marine than in eastern Texas where the upper Jackson is a littoral facies.

In the Westmoreland well, southwest of Houston, the *Textularia warreni* beds are 670 feet thick. At Fairbanks they are 400–425 feet thick, and at Tomball they are generally between 300 and 400 feet thick. As in the Jackson, a larger amount of formational thickening occurs in the area between the Westmoreland well and Fairbanks than in the area north of Fairbanks. The *Textularia warreni* beds thicken at the rate of 20 feet per mile in the former area, and, if this rate of thickening continues southward, these beds are 1,490 feet thick at the present shore line.

Lithologic character.—The *Textularia warreni* beds are composed of shale, sandy and silty shale, sand, and sandstone. In the northern part of Harris County, Texas, approximately 25 per cent of the beds are sand, sandstone, or sandy shale whereas in the southern part of the county sediments of these types make up 10 per cent of the total.

The shale varies in color from dark gray to greenish gray, and much of it is lignitic. The washed residue of nearly all the shale beds contains a small amount of siltstone flakes. The sandstones are quartzose, and most of the grains are colorless although some are gray, bluish gray, or black.

Conditions of accumulation.—The presence of marine foraminifers and echinoid plates in the *Textularia warreni* beds shows clearly that these are marine deposits. In the lower beds where the typical Vicksburg fossils are present, Ellisor[25] found two distinct faunas. The older of these faunas is present farther inland than the younger, establishing the fact that these beds were deposited in a retreating sea. In nearly all well sections, the upper beds are sandy although the rest contains very little sand. This suggests, possibly, that this upper part is a facies nearer the shore line than the lower part. This may also account for the scarcity of foraminifers in the upper beds. A near-shore environment may not represent the optimum of conditions for Vicksburg life.

[25] Alva Christine Ellisor, *op. cit.*, p. 1324.

Paleogeography.—The shore line at the beginning of this epoch was probably within 5 miles of the present outcrop of the Catahoula-Jackson contact in eastern Texas. This conclusion, based on evidence already given, rests on the assumption that there was no beveling of these beds before the deposition of younger strata.[26] The seas gradually withdrew during the entire epoch. The lower Frio in well sections near the modern shore line is marine, and it is probable that the seas which deposited the *Textularia warreni* beds did not withdraw as far south as the present shore line. The shore line at the close of the epoch was probably in the central part of Matagorda, Brazoria, Galveston, and Chambers counties.

FRIO FORMATION

A thick sequence of clays and sandstones, which are ashy and continental at least as far south as Houston, overlies the *Textularia warreni* beds in Texas. These beds are known as the Frio formation. The strata mapped as Frio at the outcrop in southwest Texas represent only the lowermost part of the Frio as it is here defined. The rest is overlapped by the Catahoula. Some geologists place these beds in the Catahoula formation. A statement of this problem together with the reasons for retaining the Frio as a separate, older formation are given later.

The nature of the basal contact of the Frio in eastern Texas is not known as it is not known to crop out in this area. According to Plummer,[27] the Frio strata lie conformably on the Fayette in southwestern Texas. Some workers in that area, however, have found local areas where the contact appears to be unconformable. The probability is that no extensive unconformity marks the basal contact of the Frio formation.

Distribution and thickness.—The Frio formation is found in well sections from the Rio Grande to the Mississippi River. However, it is not found to crop out east of Karnes County, Texas, as the Catahoula completely overlaps the truncated surface of the Frio in the central and eastern parts of Texas.

The Frio is 1,300 feet thick in northern Harris County and is 1,886 feet thick in the Westmoreland well southwest of Houston. A well 7 miles west of Spindletop, Jefferson County, drilled 2,075 feet of Frio beds. The Frio is more than 2,000 feet thick in a well section 4 miles south of the Louise oil field in Jackson County. In the Van Vleck field, Matagorda County, one well section had 4,265 feet of

[26] See p. 192.

[27] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 705.

Frio strata. This indicates that the Frio must be more than 5,000 feet thick at the present shore line.

Lithologic character and structure.—The Frio formation in Harris County consists of strata of ashy clays, sandy and silty clays, and ashy sandstones. The sandstone content varies from Louisiana and eastern Texas to southwestern Texas. In the Cheneyville oil field, Rapides Parish, Louisiana, at least 25 per cent of the formation is sand although in Harris County, Texas, sand accounts for about 18 per cent of all beds. Plummer[28] estimates that the Frio is 95 per cent clay at the outcrop in southwestern Texas. The thickness of individual sand beds varies from a few inches to more than 100 feet. All sand bodies in the updip part are lenses of limited areal extent. It is not uncommon to find a 75-foot or 100-foot sand bed present in one well and entirely absent in a well 1,000 feet distant.

The Frio clay in the eastern and central part of the Texas Coastal Plain is characteristically ashy and light green in color. Small amounts of red and gray clay are also found. In the lower 200 or 300 feet there is a considerable amount of dark gray, lignitic shale. Well sections in Brooks County show that the clay is largely red in color. The sand grains are angular to subangular and many have a glassy luster. In the lower part of the Frio are two or three zones of "rice sand." The grains in these zones are coarse and composed of milky quartz. These rice sands are lenticular and can not be used for correlation. In Brooks County well sections, the sands are very feldspathic but this characteristic is limited to the southwestern part of the Texas Coastal Plain. In this same area, the Frio contains less pyroclastic material and more calcareous material than is found elsewhere.

Conditions of accumulation.—The presence of large amounts of volcanic ash, the lack of parallel structures in the clays, the absence of marine fossils and glauconite, and the lenticularity of the sands indicate that the Frio was deposited under non-marine conditions.

Wells drilled near the modern shore, insofar as they have penetrated the Frio, show that it is marine. Here glauconite and marine fossils are universally present in the Frio. One well in the Old Ocean area of Matagorda County was drilled through 1,600 feet of marine Frio strata. The non-marine Frio in the areas along the strike of central Harris County and in the areas updip changes into a marine facies southward.

The arkosic character of the sands and the dearth of pyroclastic material in the Frio of southwestern Texas indicate a source of the sediment different from that in south-central and southeastern Texas

[28] *Ibid.*, p. 706.

where the Frio sands are non-arkosic and pyroclastic material is plentiful. The Frio of southwestern Texas was deposited by east-flowing streams, and the source must have been the outcrop of igneous rocks, as well as limestone and shale, in Mexico. This region was south of the main area of volcanic activity and received only a small amount of ashy material. The Frio of the central and eastern parts of the Texas Coastal Plain was deposited by south-flowing streams. The source of the sediment was in a region toward the north which was receiving pyroclastic material as the volcanic centers were in the belt of westerly winds. The Frio of the central and eastern part of the Texas Coastal Plain has, therefore, much reworked pryoclastic material, and it also has some that was deposited directly in the beds. As the source area for this part of the Frio had only sedimentary rocks cropping out, the sands are quartzose.

Paleogeography.—Marine deposition continued throughout all of Frio time in the region of the present shore line. The Frio seas gradually moved inland and by the close of the epoch the shore line was somewhere between the Harris County-Galveston County line and the parallel of Houston (Fig. 4). Several fossil zones have been reported in the upper 300 feet of Frio at the Hastings field in northern Brazoria County. On the other hand, the Frio in the Amerada Petroleum Corporation's Mellie Esperson well No. 1, in the Deer Park area 9 miles east of Houston, contained ash beds and abundant plant remains but no marine fossils. The shore line at the close of Frio time must, therefore, have been between these two areas.

FRIO-CATAHOULA PROBLEM

The age of the Frio and the correlation of the subsurface Frio with outcropping beds are in question and a subject of controversy among Gulf Coast geologists.

The Frio is overlain by a marine wedge in an area extending inland from the present shore line approximately 80 miles in eastern Texas and considerably less than 80 miles in southwestern Texas. The marine wedge is divided into the *Marginulina*, *Heterostegina*, and *Discorbis* zones. Above the marine wedge is a sequence of pyroclastic and fluviatile beds generally called the subsurface Catahoula. The surface Catahoula also is composed of pyroclastic and fluviatile sediments. It rests unconformably on the Jackson in the central and eastern parts of the Texas Coastal Plain and unconformably on the Frio in southwestern Texas.

In attempting to correlate the subsurface beds from the base of the Frio to the top of the Catahoula with outcropping beds, three possibilities arise.

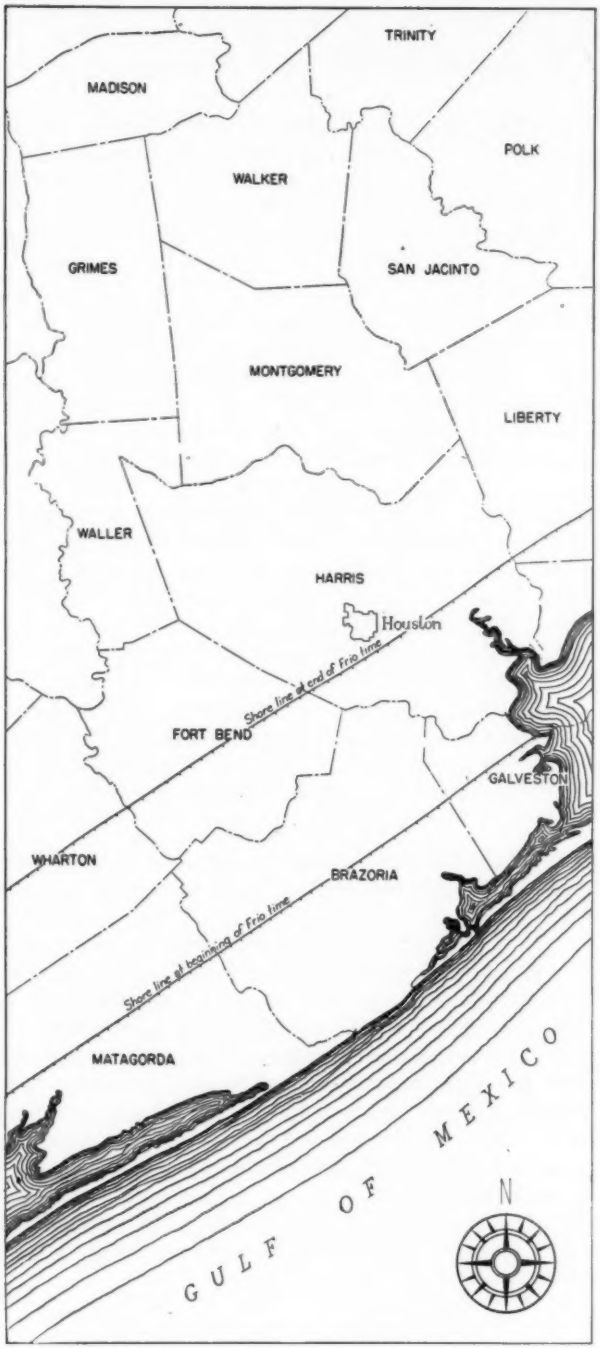


FIG. 4.—Paleogeographic map for Frio time.

First, the surface Catahoula may be the equivalent of the subsurface Frio, making the subsurface Catahoula the equivalent of the lower part of the surface Fleming.

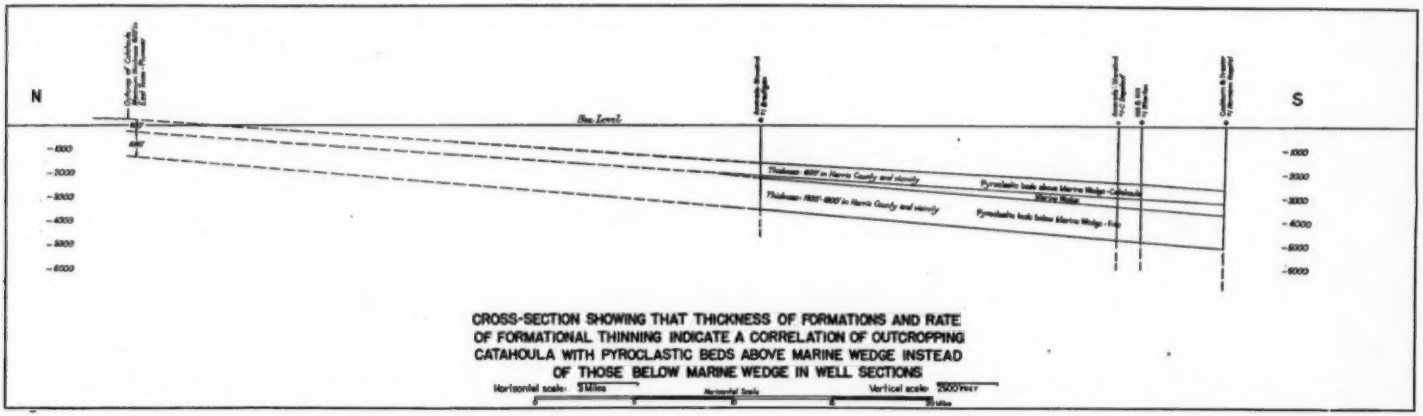
Second, the surface Catahoula may be correlated with all the beds between the base of the subsurface Frio and the top of the subsurface Catahoula.

Third, the surface Catahoula may be the equivalent of the subsurface Catahoula—the pyroclastic deposits above the marine wedge—in which case the truncated surface of the Frio would be completely overlapped by the Catahoula in the eastern and central parts of the Texas Coastal Plain and partly overlapped by the Catahoula in southwestern Texas.

Sufficient evidence is now available to eliminate the first possibility. Dip sections in San Patricio, Bee, and Live Oak counties show that the clearly discernible Catahoula-Fleming contact in well sections can be traced updip to the surface exactly where the Catahoula-Fleming (Catahoula-Oakville) contact has been mapped at the surface. The well sections are sufficiently close together and the contact sufficiently clear to make the tracing of this contact from subsurface sections to the surface indisputable. The subsurface Catahoula can not, therefore, be correlated with the lower part of the surface Fleming, eliminating the correlation of the surface Catahoula *in toto* with the subsurface Frio.

Another fact unfavorable to the first possibility is made clear by projecting toward the outcrop the observed rate of thinning of the subsurface Catahoula and Frio in the area where the marine wedge is present to see which series of beds has a thickness more consistent with the observed thickness of the Catahoula at the outcrop (Fig. 5). The Catahoula is 200–300 feet thick at the outcrop north and northwest of Harris County. It thickens to about 600 feet east and 800–1,000 feet southwest of this area. The probability is that 600 feet represents the true thickness of the Catahoula in the first area mentioned because there is an unconformity at the top of the Catahoula and the Fleming seems to overlap the Catahoula in this area.

The most northerly well section with the marine zone present that could be found in eastern Texas is in southern Montgomery County just north of the Tomball oil field. The marine zone is only 40 feet thick in this well section and the Frio is 1,300 feet thick. In a well section 19 miles south the Frio is 1,460 feet thick. This is a thinning of 8.4 feet per mile. If this rate of thinning is projected to the outcrop, the Frio should be 1,025 feet thick there. Nowhere in eastern and central Texas is there such a great thickness of Catahoula beds at the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CROSS-SECTION SHOWING THAT THICKNESS OF FORMATIONS AND RATE OF FORMATIONAL THINNING INDICATE A CORRELATION OF OUTCROPPING CATAHOULA WITH PYROCLASTIC BEDS ABOVE MARINE WEDGE INSTEAD OF THOSE BELOW MARINE WEDGE IN WELL SECTIONS
Horizontal scale: 5 Miles
Vertical scale: 2500 Feet

FIG. 5.—Cross section showing that thickness of beds indicates correlation of surface Catahoula with pyroclastic beds above marine wedge.

surface. On the other hand, the strata containing pyroclastic material above the marine wedge are approximately 600 feet thick anywhere in the vicinity of Harris County. These beds thicken little if any shoreward. It is apparent that the thickness of the subsurface pyroclastic beds above the marine wedge is nearly identical with the maximum thickness of the surface Catahoula in eastern Texas although the

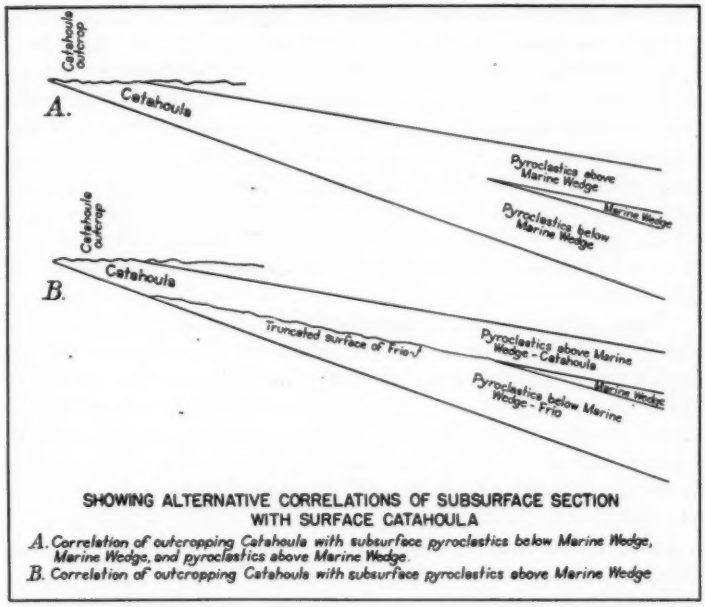
Catahoula outcrop
A.
Catahoula
Pyroclastics above Marine Wedge
Marine Wedge
Pyroclastics below Marine Wedge
Catahoula outcrop
B.
Catahoula
Truncated surface of Frio
Pyroclastics above Marine Wedge - Catahoula
Marine Wedge
Pyroclastics below Marine Wedge - Frio
SHOWING ALTERNATIVE CORRELATIONS OF SUBSURFACE SECTION WITH SURFACE CATAHOULA
A. Correlation of outcropping Catahoula with subsurface pyroclastics below Marine Wedge, Marine Wedge, and pyroclastics above Marine Wedge.
B. Correlation of outcropping Catahoula with subsurface pyroclastics above Marine Wedge

FIG. 6.—Alternative correlations of surface Catahoula and subsurface section.

subsurface Frio beds are much too thick to be correlated with the surface Catahoula.

The Catahoula-Frio problem is thus reduced to the two alternatives shown in Figure 6. Either the surface Catahoula is equivalent to all subsurface beds from the base of the Frio to the top of the pyroclastic deposits above the marine wedge, or it is the equivalent only of the pyroclastic beds above the marine wedge, that is, the subsurface Catahoula. Fortunately, critical evidence is to be found in the lithologic character of the deposits in question.

The amount of pyroclastic material increases greatly toward the southwest in the surface Catahoula but it decreases greatly toward the

southwest in the subsurface Frio. Plummer[39] states that in the surface Catahoula

> pyroclastic materials predominate in the south Texas area. Boulders, pebbles, and chunks of lava, porphyry, and pumice are common in McMullen, Duval, and Starr Counties.

He believes that some of the craters

> were located in or near the southwestern part of the state because in south Texas the volcanic material is thickest and coarsest.

The subsurface Frio, on the other hand, contains very little pyroclastic material in southwestern Texas, and the pyroclastic material that is present is fine. It seems impossible that such a change in the amount and texture of this material could take place in the few miles between the outcrop and well sections downdip. Southwestern Texas thus appears to have been remote from volcanic craters during the time of the deposition of subsurface Frio beds and near the craters during the time of deposition of the surface Catahoula beds. The subsurface Frio can not therefore be contemporaneous with any part of the surface Catahoula.

The absence of any conspicuous intraformational hiatus in the Catahoula that could be contemporaneous with the retreat of the sea during late *Heterostegina* and *Discorbis* time suggests that the Catahoula is post-*Discorbis*. An uplift sufficient to cause the sea to retreat nearly 65 miles would probably cause such an interruption in sedimentation at the site of the present outcrop that a conspicuous hiatus would now be visible in the exposed section. If the Frio and the marine wedge were Catahoula in age the hiatus would be within the outcropping Catahoula. No such hiatus is found in the Catahoula, but a major unconformity is found at its base. The most probable assumption is that the same uplift that caused the formation of this basal unconformity caused the seas to retreat during late *Heterostegina* and *Discorbis* time. If this is true, the surface Catahoula is the equivalent of the pyroclastic strata above the *Discorbis* zone in the subsurface section.

The facts thus indicate that the Frio is older than the Catahoula. Observed conditions are best explained with the idea that the Catahoula completely overlaps the truncated surface of the Frio in central and southeastern Texas and partly overlaps it in southwestern Texas. Only in this way can the radical difference between the distribution of pyroclastic material in the surface Catahoula and the subsurface Frio be explained. Likewise, this is the only correlation that will give a major hiatus updip to correspond with the retreat of the *Heterostegina-*

[39] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 720.

Discorbis sea. The writer, therefore, correlates the surface Catahoula with the pyroclastic deposits above the marine wedge and retains the Frio as a separate formation older than the Catahoula.

The present difficulty in understanding the stratigraphic relationship of the Frio arises in part from the fact that the classification of the beds in this part of the section was based on data from well sections some distance inland where the Frio is continental. These wells went through the continental Catahoula, then through the marine wedge, and into the continental Frio. The *Marginulina* zone was defined as those beds above the non-marine strata as high in the section as *Marginulina* sp. is found. Now that deep wells have been drilled near the shore where the Frio is all marine, it is not surprising that fossils typical of the *Marginulina* zone are found in beds older than the lowest *Marginulina* beds inland. In other words, the lower limit of the fauna of the *Marginulina* zone in areas farther inland was determined by the geographic conditions of the times rather than by the distribution of this species in time. Although it is true that some *Marginulina* zone fossils are found in wells near the modern shore line in beds that grade updip into the upper part of the continental Frio, it is not correct to call the entire Frio the continental equivalent of the *Marginulina* zone as that zone has previously been defined. The correct approach to this problem is to study the deep-well sections along the coast, where all the beds are marine, and to correlate the several stratigraphic units there with the marine type sections elsewhere. Until a definition of the *Marginulina* zone is made that is applicable both updip and downdip, it is useless to attempt to say how much of the Frio is the equivalent of the lower *Heterostegina* and *Marginulina* zones. That the entire Frio will be found to be the equivalent of the *Marginulina* zone, as that latter term is now generally used, is highly improbable. The logical view to take of these non-marine beds between the *Textularia warreni* beds and the *Marginulina* zone is that the uppermost part is the non-marine equivalent of the lower *Heterostegina* zone and the *Marginulina* zone and that the lowermost part is the non-marine equivalent of the *Textularia warreni* beds which were deposited in a retreating sea. A possible exception to the latter is the possibility of a hiatus in the section updip which is contemporaneous with the *Textularia warreni* beds. Just how much is left after the equivalents of the overlying and underlying marine beds have been taken away is not yet known, but it probably represents the greater part of the entire non-marine zone, and this part must be considered a separate formation. It is convenient, although admittedly arbitrary, for practical working purposes in the

inland areas, to extend the limits of the Frio formation to include all the continental deposits between the marine wedge and the *Textularia warreni* beds. Although this may be acceptable as a working definition, one should not lose sight of the time relationships of the upper and lower parts of this zone.

As the strata mapped as Frio at the surface in southwestern Texas represent only the lower part of the entire formation, the remainder being overlapped, it is probable that part or all of these beds at the outcrop are the continental equivalent of the *Textularia warreni* beds downdip. The key to this problem is in the presence or absence of a hiatus at the base of the surface Frio.

MIOCENE SERIES

MARINE LOWER MIOCENE

Extensive drilling operations in the Gulf Coast have revealed the existence of a wedge of marine sandstones and shales between the Frio and Catahoula formations, which is entirely absent in the outcrop. These beds have been placed in the Oligocene by most writers on Gulf Coast stratigraphy because of certain Oligocene affinities in the fauna. Recently, however, many Gulf Coast paleontologists have recognized probable Miocene affinities in the fauna of these beds. Their definite assignment to either series is rendered exceedingly difficult because Foraminifera are almost the only available fossils from these subsurface beds, and the basis for the original subdivision of the Tertiary in Europe was the ratio between living and extinct species of Mollusca. Conclusive evidence appears to be lacking at this time and only a tentative correlation can be made. However, of the two main faunal characteristics observed, namely, the continuation of typical Oligocene forms and the influx of typical Miocene forms, the latter is the more significant as far as age determination is concerned, and these beds are, for the present, taken out of the Oligocene and placed in the Miocene.

This does not necessarily mean that they can be correlated with any known surface formation of Miocene age. It is altogether possible that these subsurface strata are not the equivalent of any described outcropping formation. Further credence is attached to this idea by the fact that a major unconformity marks the Miocene-Oligocene contact at the outcrop in Texas. This opens the possibility that these strata are Miocene in age but older than the Catahoula, the oldest outcropping Miocene formation, having been deposited, in part, while the hiatus was being formed in the region now occupied by the outcrop.

The key to the solution of this problem is the determination of the subsurface equivalent of the outcropping Catahoula. If the pyroclastic deposits above the marine wedge are the time equivalent of the Catahoula, that part of the marine wedge which was deposited in a retreating sea is contemporaneous with the hiatus at the base of the Catahoula and is transitional between the outcropping Oligocene and Miocene.

Under the discussion of the Frio, evidence was presented which seems to indicate the equivalency of the Catahoula and the pyroclastics above the marine wedge. It is, therefore, conservative to say that these facts justify a serious consideration of the idea that the upper part of the marine wedge is contemporaneous with the hiatus at the base of the Catahoula and that the entire marine wedge, although post-Oligocene in age, is older than the oldest outcropping Miocene beds.

Fossil zones.—The marine wedge has been divided into three widely recognized fossil zones. From the oldest to the youngest these are the *Marginulina* zone, the *Heterostegina* zone, and the *Discorbis* zone. Key fossils for these are *Marginulina mexicana* var. *vaginata* Garrett and Ellis, *Heterostegina israelskyi* Gravell and Hanna and *Heterostegina texana* Gravell and Hanna, and *Discorbis* cf. *D. vilardeboana* d'Orbigny, respectively.

The top of the *Heterostegina* zone is perhaps the best datum above the McElroy for structural contouring. It extends a considerable distance inland, appears to be at a very consistent stratigraphic level, and its fauna is easily recognized. The only difficulty in mapping on this zone is the absence of a lithologic change at its top, making impossible its recognition in Schlumberger logs.

Thickness and distribution.—The thickness of this formation varies from 0 feet in southern Montgomery County, where it wedges out, to 3,395 feet in southern Galveston County. At Tomball these beds are 40 feet thick, at Fairbanks 320 feet thick, and in southern Harris County and northern Brazoria County they are 850 feet thick. In the Shell Petroleum Corporation's Maco Stewart well No. 1, in southern Galveston County, this wedge has a thickness of 3,395 feet.

These beds have a wide areal distribution. They occupy a belt extending from Mississippi to southwestern Texas. The marine wedge does not appear at the surface; it is found only in well sections.

Lithologic character.—Shales, sands, and locally, limestone lentils make up the marine wedge. The relative amount of sand varies locally. At Fairbanks the formation is 31 per cent sand, southwest of Houston it is 10 per cent sand, and in northern Brazoria County the

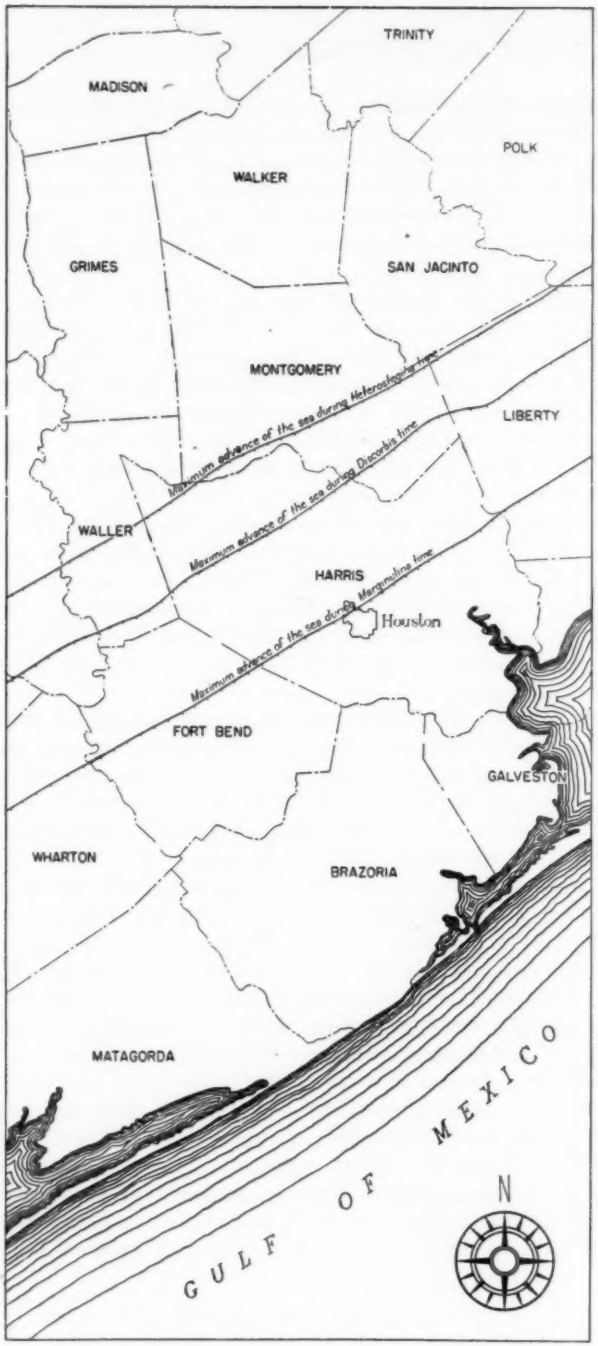

FIG. 7.—Paleogeographic map for *Marginulina*, *Heterostegina*, and *Discorbis* times.

formation is barren of sand except in its extreme upper and lower parts. From Victoria County, Texas, southwestward and in Louisiana, the central and lower parts of this zone contain well developed, oil-bearing sands.

Limestone bodies are found in the *Heterostegina* zone which appear to be reefs deposited on local submarine elevations while the sea had reached its maximum of invasion. They are found now most commonly around salt domes relatively near the modern shore line. A well on the flank of Stratton Ridge dome in southern Brazoria County encountered 1,675 feet of *Heterostegina* limestone. Post-*Heterostegina* uplift has, however, given a secondary dip to this limestone body, and its true thickness is, therefore, considerably less than the observed thickness.

The shales are predominantly gray although some are brown or greenish. Generally they contrast markedly with the overlying buff Catahoula tuffs and clays and with the underlying green Frio clays. The shales are fossiliferous, glauconitic, and generally micaceous and calcareous. The sandstones are quartzose and very similar to the sandstones of the previously described marine formations.

Conditions of deposition.—The presence of marine fossils and glauconite everywhere in this formation proves its marine origin. This conclusion is substantiated by the presence of continuous blanket sands in the region southwest of Jackson County, Texas, and also in Louisiana. As the *Heterostegina* zone extends farther inland than either the lower or higher zones in eastern Texas, the *Marginulina* and lower *Heterostegina* beds must have been deposited in a transgressive sea and the upper *Heterostegina* and *Discorbis* beds must have been deposited in a regressive sea. In Louisiana and southwestern Texas, the maximum advance of the sea may have been in *Discorbis* time.[30]

Paleogeography.—The *Marginulina* zone is found in well sections in Clinton and Deer Park due east of Houston but is absent at Eureka and Fairbanks a short distance northwest of Houston. The shore line at the end of *Marginulina* time was in the area now occupied by the northwestern city limits of Houston and followed the present strike of the beds (Fig. 7). By middle *Heterostegina* time the seas had advanced to the area now occupied by southern Montgomery County. A test drilled on the north flank of the Tomball structure encountered 40 feet of *Heterostegina* beds. The maximum of invasion was reached during middle *Heterostegina* time after which the seas retreated. At the beginning of *Discorbis* time the strand line was along the strike of Bammel 7 or 8 miles south of Tomball. Its exact position at the

[30] See p. 192.

close of *Discorbis* time has not been determined, but it was near central Brazoria and Matagorda counties.

The focal point of the uplift which caused this retreat was in eastern Texas as the maximum advance of the sea was reached at a slightly earlier time there than in Louisiana and southwestern Texas.

CATAHOULA FORMATION

A series of strata composed largely of pyroclastic material interstratified with fluviatile deposits is found above the *Discorbis* zone in well sections, above the Frio in the outcrop in southwestern Texas, and above the Fayette in outcrop in eastern Texas. This series is generally called the Catahoula but contemporaneity with the Catahoula of Mississippi and Louisiana has not been definitely established. Howe[31] considers the Catahoula to be Lower Miocene in age. This is confirmed by the Miocene affinities in the fauna of the underlying beds.

The relationship of the outcropping Catahoula with the subsurface beds downdip has been discussed previously. The preponderance of evidence favors the correlation of the outcropping beds with the 600 feet of pyroclastic strata found above the *Discorbis* zone everywhere in Harris County and areas along the strike. Near the present shore line the Catahoula grades into a marine series with a fauna which is difficult to distinguish from the fauna of the *Discorbis* zone.

The basal contact of the Catahoula in the outcrop is unconformable. Eastward from Karnes County the Catahoula completely overlaps the Frio, and in places in central Texas it overlaps a part of the Fayette. The Frio is exposed in southwestern Texas but the Frio-Catahoula contact is unconformable.

Distribution and thickness.—The Catahoula outcrop is continuous in Texas from the Rio Grande to the Sabine River. Likewise a series of pyroclastic beds is encountered above the *Discorbis* zone in well sections everywhere south of the outcrop.

The thickness of the Catahoula is difficult to determine in well sections where the marine wedge does not occur between it and the Frio because of the similar appearance of these two formations. The upper contact is placed at the top of the first pyroclastic bed. This may not be an accurate definition of the upper limit of the subsurface Catahoula everywhere because the lower part of the Fleming contains some pyroclastic material. The probability is, however, that in eastern Texas no great error is made by thus defining the upper contact of the subsurface Catahoula.

[31] Henry V. Howe, "Louisiana Petroleum Stratigraphy," *Louisiana Dept. Conserv. General Minerals Bull. 27* (1936), p. 30.

The Catahoula at the outcrop is thinnest in central Texas, being 100–200 feet thick in Gonzales, Fayette, and Washington counties. It thickens both eastward and southwestward, thicknesses ranging from 300 to 600 feet having been reported in eastern Texas and from 800 to 1,000 feet in southwestern Texas.

This formation appears to thicken little if any gulfward. The pyroclastic beds above the *Discorbis* zone are 600 feet thick in the extreme southern part of Montgomery County and in most of Harris County. At the Van Vleck oil field, Matagorda County, a series of interstratified pyroclastic continental and marine deposits overlies the *Discorbis* zone. This is probably the equivalent of the Catahoula where it is grading into a marine facies. This zone is 700 feet thick.

Lithologic character.—The Catahoula is an interstratification of pyroclastic material and fluviatile sediments. The rocks are tuff, tuffaceous, or ashy sand, ashy clay, sandy clay and clay. The pyroclastics predominate.

Schlumberger logs show that 25 per cent of the formation is a coarse-textured deposit at Tomball and 30 per cent at Fairbanks. Most of the sand is concentrated into the bottom part of the formation with only a few thin sand beds occurring above. This sand body is frequently called the basal Miocene sand and can be readily recognized along the strike of Harris County in the eastern part of the state. Near the modern shore line, the upper part of the *Discorbis* zone is sandy so that the base of the formation is not readily determined by lithologic character. In some structures the basal sand becomes very thick and is petroliferous. It is 350 feet thick at the Hastings field.

The sandstone strata are in many places cross-bedded, generally very ashy, and locally much indurated. Opal, silica, and argillaceous material are common cementing materials. Individual beds may grade horizontally from a well indurated sandstone into an unconsolidated deposit. Bailey[32] reported the following mineral composition of an upper Catahoula sandstone in Tyler County.

	Per Cent		*Per Cent*
Quartz	30	Magnetite	1
Plagioclase (mainly andesine)	28	Biotite, volcanic glass, muscovite, and zircon	Trace
Chert	25	Opal (from cement)	11
Orthoclase and sanidine	4		
Microcline	1		

The compositions of Catahoula sandstones vary greatly, however, and no generalizations can be made. Bailey reported as much as 70 per cent quartz in a sand in Gonzales County.

[32] Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas," *Univ. Texas Bull. 2645* (1926), p. 145.

Most of the quartz grains are subangular or subround and are colorless. Some of the beds contain "rice sands" which resemble the "rice sands" of the Frio.

The volcanic tuffs are white, buff, gray, or greenish gray, are massive, and some types break with a conchoidal fracture. The Catahoula tuffaceous beds may grade from pure tuff into tuffaceous clays and tuffaceous sand. Some of the tuffs are highly silicified in which case they are relatively resistant and break with a conchoidal fracture. Some appear to be an altered form and may even be reworked. Lava boulders are found in many places in them in southwestern Texas. Bailey[33] gives the following composition for a sample of white tuff from Live Oak County.

	Per Cent		*Per Cent*
Volcanic glass	70	Opal	1
Soda-lime feldspar	20	Quartz, magnetite, marcasite, zircon, apatite, chlorite, barite, serpentine (?), witherite	Trace
Sanidine	5		
Leverrierite aggregates	4		

The Catahoula clays in central and eastern Texas are generally buff, gray, or green in color and they are commonly very ashy. These clays are commonly red in the extreme southwestern part of the state and resemble the red Frio clays.

Conditions of accumulation.—Volcanic centers in the west were exceedingly active during Catahoula time. The ejected material was deposited widely over the western part of the Gulf Coastal Plain. Much of the material has been reworked by the Coastal Plain streams of the time. These streams deposited some non-pyroclastic material also. Rarely, however, are the fluviatile deposits found to be entirely free of tuff, indicating that the volcanic activity was almost continuous. The feldspar in the sands indicates that the source of the non-pyroclastic deposits was near the Coastal Plain. The streams in eastern Texas were more vigorous than those in the west in the latter part of Catahoula time, and more sand was deposited in the former area than in the latter.

Fossils are not common in the continental facies of the Catahoula. Unios and a number of fossil plants have been observed in some beds. Berry[34] reports a relative abundance of palms which indicates a tropical climate.

Paleogeography.—The Catahoula is rarely cored in well sections so that good descriptions of this formation in downdip well sections are lacking. It appears certain, however, that the Catahoula along the

[33] Thomas L. Bailey, *op. cit.*, pp. 128–29.

[34] Edward Wilber Berry, "The Flora of the Catahoula Sandstone," *U. S. Geol. Survey Prof. Paper 98* (1916), pp. 227–51.

strike of Harris County is continental. This is indicated by the ash beds and the absence of marine fossils and glauconite. Previous mention has been made of the presence of 700 feet of section above the *Discorbis* zone at Van Vleck which contains both marine and nonmarine beds. The ash and bentonite in these beds indicate that this is the equivalent of the pyroclastic deposits above the *Discorbis* zone in Harris County, which in turn is correlated with the surface Catahoula. The Catahoula shore line thus appears to have been in central or northern Matagorda, Brazoria, and Galveston counties.

MIOCENE AND PLIOCENE SERIES

FLEMING GROUP

The Fleming group, which overlies the Catahoula, is a sequence of mottled calcareous clays and sands. Southwest of the Brazos River it has been divided into the Oakville sand below and the Lagarto clay above. In southeastern Texas, however, the Oakville changes into a clayey facies which can not be distinguished from the Lagarto clay either in the outcrop or in well sections. For this reason all the Fleming strata are grouped together in the discussion which follows.

Fleming strata are distinguished from the Catahoula by the presence of reworked Cretaceous fossils and large amounts of calcium carbonate in the clays and sands and by the dearth of pyroclastic material. In central and southwestern Texas, the basal Oakville contains some pyroclastic material but this was probably derived largely from the Catahoula. There is little ash in the Fleming of southeastern Texas. It is distinguished from overlying strata by the presence of reworked Cretaceous fossils.

The basal contact of the Fleming is unconformable at the outcrop. Locally a basal conglomerate is present. The upper part of the Catahoula in south-central Texas is overlapped by the Fleming. As in the case of other Tertiary formations, the gulfward extent of this hiatus is unknown.

Distribution and thickness.—This group of strata occupies a continuous belt along the margin of the Texas Gulf Coastal Plain. It is found in every well section south of the outcrop except in those located over salt plugs which have pierced it.

The following list shows the thickness of the Fleming in a series of well sections in Montgomery, Harris, and Brazoria counties.

	Thickness in Feet
Stanolind Oil and Gas Company-Amerada Petroleum Corporation's Fred Brautigan No. 1, southern Montgomery County	1,300
Cockburn and Frazier's Herman Hospital No. 1, 3 miles southeast of Addicks, Harris County	1,685

Capps, Benedum and Trees' Westmoreland No. 1, 5 miles west of Bellaire, Harris County 2,224
Amerada Petroleum Corporation's Houston Farms Development Company No. 1, southern Brazoria County 4,000

As stated previously, there is some doubt as to the downdip equivalent of the Catahoula. This affects the thickness of the Fleming reported in the last well. If the downdip equivalent of the Catahoula is the upper part of the Miocene *Discorbis* zone, then the Fleming in the last-listed well is 4,700 feet thick.

Lithologic character.—The Fleming is composed of sandstone and calcareous, mottled clay. The relative amount of sand varies. Generally, there is less in southeastern Texas than in the southwestern part of the state. At Fairbanks it is approximately 25 per cent sand and at Rattlesnake Mound in southern Brazoria County it is approximately 35 per cent sand.

The sand grains are predominantly quartz, but calcareous nodules are very common, and cementing material is in many places calcite. The sandstone strata are lenticular and generally more friable than well indurated, but in southwestern Texas the Oakville sandstones are sufficiently strong and continuous to form the Bordas cuesta. No equivalent of this escarpment is present in eastern Texas because clays replace the sandstones east of the Brazos River. Most of the Fleming sands are intricately crossbedded.

The clays are calcareous and mottled. Tan, red, green, purple, and gray are common colors. They are poorly bedded and contain many calcareous concretions and reworked Cretaceous fossils.

Conditions of deposition.—The Fleming is a fluviatile complex laid down upon the eroded, south-sloping surface of the Catahoula. Some of the deposits show a deltaic structure, but much of it is channel deposit of many widely meandering streams.

The sudden influx of great amounts of calcareous material at this time together with the presence of reworked Cretaceous fossils in Fleming beds shows that the region of the Cretaceous outcrop was abruptly uplifted and was in part the source of the Fleming deposits. The Cretaceous fossils present include both Foraminifera and macrofossils. The Fleming in well sections near the present shore contains glauconite and late Tertiary Foraminifera, indicating that a marine facies is present.

Paleogeography.—The younger beds encountered in most wells are so poorly logged that sufficient, accurate data are not available for the determination of the exact position of the Fleming shore line. These beds are almost entirely continental along the strike in Harris County. In the Amerada Petroleum Comporation's Houston Farms

Development Company well No. 1, in southern Brazoria County, however, Miocene Foraminifera are present throughout the Fleming and other wells along the strike show the same condition. The Fleming is unquestionably marine at the site of the present shore line. The probability is that except for minor fluctuations the Fleming shore line passed through the central or northern part of the most southerly tier of counties.

PLIOCENE SERIES

WILLIS FORMATION

The post-Fleming formations can not be differentiated in most well sections, and the study of this part of the section is consequently based on surface data. If cored sections were available a subsurface study of these beds would undoubtedly be possible. However, they are generally neither cored nor sampled except in rare cases where special core tests are drilled for correlation purposes, and the data from such core tests is generally not available for publication.

The name "Willis" was first proposed by Doering[35] for the strata between the Fleming and the Pleistocene. Plummer[36] had previously recognized these strata as distinct from either the Fleming or the Lissie, but he did not name them. The Willis has been recognized under that name as a valid formation on the 1937 geologic map of Texas.

According to Doering, this formation is the equivalent of the upper Citronelle. Although most of it is probably younger than the Goliad of southwestern Texas, the lower part of the Willis may be the equivalent of the upper part of the Goliad.

The basal contact is unconformable. The underlying formation in southeastern Texas is the Lagarto, but in places in central and southwestern Texas it is probably the Goliad.

Distribution and thickness.—The Willis has been mapped in Texas from the Colorado River to the Sabine River, but strata belonging to this formation are also present southwest of the Colorado River. It also occupies a discontinuous belt across southern Louisiana. Wherever a stream of any size crosses the Willis belt, the beds are either eroded away or covered, giving an irregular pattern to the outcrop area.

Doering states that the Willis is 80–85 feet thick in southeastern

[35] John Doering, "Post-Fleming Surface Formations of Coastal Southeast Texas and South Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 651–88.

[36] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, pp. 761–62.

Texas and southwestern Louisiana and 120–125 feet thick in southeastern Louisiana.

Lithologic character.—The Willis is composed of alluvial gravels, sands, and clays. The gravels and sands are quartzose and generally light-colored and cross-bedded. In a section north of Tomball, many ferruginous nodules are disseminated through the sand. The sand is red and somewhat indurated. The sands in other parts of the formation are light gray. Willis clays are generally disseminated through the sands and gravels, but a few clay beds are present in the formation.

Doering has recognized three lithologically distinct members in the Willis formation. The reader is referred to his paper for detailed descriptions of these members.

Conditions of accumulation.—All outcropping beds of the Willis are fluviatile in origin. They were deposited upon the eroded surface of the older beds after a down-warping of the coastal border brought about a change from a cycle of denudation so one of deposition. The presence of Catahoula material in Willis beds and the presence of isolated remnants of Willis strata over the Fleming outcrop suggest that it was deposited seaward from the Catahoula scarp by streams that had cut through this cuesta. These streams deposited their load of coarse and fine sediment widely over the flat surface behind the scarp. Subsequent erosion has reduced the outcrop to its present limits.

PLEISTOCENE SERIES

HOUSTON GROUP

The name "Houston" was first proposed by Plummer[37] for the group of formations which make up the Pleistocene in the Texas Gulf Coast. The outcrop of the Houston group in eastern Texas is generally limited on the north by the Hockley scarp and on the south by Recent beach deposits. It occupies a continuous belt from the Rio Grande to the Sabine River. Equivalent beds are present in Louisiana. The Houston group has been divided into the Lissie and Beaumont formations.

LISSIE FORMATION

The Lissie formation is a sequence of gravels, sands, sandy clays, and clays, and lies above the Willis. It is limited by unconformities at both its upper and lower contacts and is distinguished from the underlying Willis formation by a generally finer texture and from the overlying Beaumont formation by a generally coarser texture.

[37] *Ibid.*, p. 780.

The Pleistocene age of the Lissie is suggested by the following list of Lissie fossils prepared by Plummer.[38]

Trucifelis fatalis Leidy	*Elephas columbi* Falconer	*Equus semiplicatus* Cope
Canis sp.	*Elephas primigenius* (Blumenbach)	*Equus excelsus* Leidy
Cistudo marnockii Cope	*Elephas imperator* Leidy	*Equus occidentalis*? Leidy
Megatherium sp.	*Equus complicatus* Leidy	Camelid
Bison latifrons (Harlan)	*Equus francisci* Hay	Ox
Mastodon serridens Cope	*Equus crenidens*? Cope	Tapir
Glyptodon petaliferus Cope	*Equus tau*? Owen	

Distribution and thickness.—The outcrop of the Lissie is continuous across the Texas Coastal Plain. In a general way, the inner limit of the outcrop is at the foot of the Hockley scarp, but in the larger stream valleys in the eastern part of the state it extends farther north in tongues which cover the Willis and part of the Fleming. This condition is shown clearly on the geologic map of Texas published in 1937.

Wells drilled near the southern limit of the Lissie outcrop show a combined thickness of more than 1,000 feet for the Lissie and Willis formations in the vicinity of Harris County. The amount that belongs to the Willis and Lissie, respectively, can not be determined as well cuttings do not show a recognizable difference between these formations. Plummer[39] attributes a thickness of 600 feet to the Lissie in eastern Texas and 400 feet in southwestern Texas. The combined thickness of the post-Fleming strata at Rattlesnake Mound, southern Brazoria County, is 2,060 feet. Again it is not possible to determine how much of this belongs to the Lissie and how much to the Willis and Beaumont.

Lithologic character.—The Lissie beds are gravel, sand, sandy clay, and clay. Sand predominates, making up more than 50 per cent of the formation. The amount of gravel is less than early descriptions of the formation indicate because Willis beds were then included. Probably not more than 15 per cent of the Lissie is gravel and some estimates are considerably less than this. Plummer[40] states that the Lissie "is made up of about 60 per cent sand, 20 per cent sandy clay, 10 per cent gravel, and 10 per cent clay."

The sands are quartzose, in many places cemented with clay, and are cross-bedded. Red, orange, buff, and gray are the common colors of the Lissie sands. The gravels occur in lenses, and the pebbles are composed of chert and quartz, and in some places fragments of igneous and metamorphic rocks.

[38] *Ibid.*, p. 787.

[39] *Ibid.*, p. 783.

[40] *Ibid.*, p. 785.

Lissie clays are mottled red, orange, green, blue, and gray. They resemble the Beaumont clays but make up a much smaller proportion of the formation than they do in the Beaumont.

Conditions of deposition.—The fauna of the Lissie at the outcrop shows that it is non-marine in origin. Streams which cut through the Willis cuesta deposited alluvial fans which coalesced to form a continuous débris apron behind the cuesta. This was laid down upon the eroded surface of the Willis. Lissie sands were also deposited in the gaps and in terraces in front of the Willis cuesta. Southward these alluvial deposits merge into deltaic and marine deposits. Marine shell fragments are found throughout the Lissie in well sections near the modern shore line and marine microfossils are reported to be present in some of the shale beds.

Bailey[41] and Plummer[42] believe that the alluviation during Lissie time was a direct result of glaciation. The coarse deposits of the Lissie indicate that the Coastal Plain streams of that time were very vigorous. This, in turn, may mean a very humid climate which could have been a result of a glacial epoch. However, it is not sufficient to predicate such a thesis merely on the fact that coarse sediments were deposited, for the Pliocene contains sediments equally as coarse. Although the Pleistocene was generally humid because of the glacial epochs, the Lissie time interval probably includes both glacial and interglacial epochs.

BEAUMONT FORMATION

The Beaumont is a sequence of clays and fine sands in a belt along the outer border of the Texas Coastal Plain. It includes all strata above the Lissie and below the Recent deposits. Both upper and lower contacts are unconformable. The Beaumont is distinguished from the Lissie by its much greater clay content and by the absence of gravel. It is also unlike the Lissie in the structure of some of the sand bodies. Surface exposures of sand in the Beaumont of eastern Texas are largely confined to long narrow belts which are believed to be abandoned distributaries.

Distribution and thickness.—The Beaumont occupies a continuous belt along the border of the Coastal Plain extending from the Rio Grande to the Sabine River. This belt is 40–50 miles wide in eastern Texas. Like the Lissie, it extends northward in irregular tongues in the major stream valleys. The equivalent of the Beaumont is also found in Louisiana.

[41] Thomas L. Bailey, "The Geology and Natural Resources of Colorado County," *Univ. Texas Bull. 2333* (1923), pp. 111–13.

[42] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, pp. 784–85.

Although the Beaumont-Lissie contact can rarely be established beyond question in well sections, Plummer[43] estimates that the thickness of the Beaumont varies between 450 and 900 feet and that the average thickness is 700 feet. These estimates appear to be reasonable in view of the fact that the combined thickness of post-Fleming strata is approximately 2,000 feet in southern Brazoria County and approximately 1,200 feet in central Harris County.

Lithologic character.—The Beaumont is composed of calcareous, mottled clays and sand and silt. The clays predominate in eastern Texas, comprising as much as 80 per cent of the formation in some places. More sand has been reported to be present in the Beaumont of southwestern Texas.

The clays are red, pink, green, tan, blue, and gray. In most places they are plastic and calcareous. Bailey[44] made the following analysis of a sample taken from the west bank of the Colorado River 9 miles southeast of Garwood.

	Per Cent		*Per Cent*
Clay	79	Feldspar	1
Calcite	10	Apatite, barite, biotite, chert, epidote, hornblende, limonite, magnetite, muscovite, zircon, carbonaceous matter, chara stems	Trace
Calcareous nodules	7		
Quartz	2		
Hematite	1		

The sands in eastern Texas are light-colored, quartzose and vary from fine to medium in texture. The sands in southwestern Texas are somewhat feldspathic.

Conditions of deposition.—Barton[45] has shown that the Beaumont of eastern Texas was formed largely by the coalescence of deltas of the Brazos, Trinity, Neches, and Sabine rivers. Low, sandy, dendritically branching ridges have been interpreted as old, abandoned distributaries. These distributaries extend inland almost to the Beaumont-Lissie contact. The Beaumont is not entirely deltaic, however, for marine and lagoonal deposits are interstratified with the delta deposits. Foraminifera and shell fragments are found in these marine beds. Coastal Plain streams were less vigorous during Beaumont time than during the preceding epoch and much of the sediment was laid down as true delta deposits in the gulf.

[43] *Ibid.*, p. 788.

[44] Thomas L. Bailey, *op. cit.*, Table 4.

[45] Donald C. Barton, "Deltaic Coastal Plain of Southeastern Texas," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 359–82.

RECENT SERIES

Recent deposits have many different facies in Texas and Louisiana. At the shore line between the Rio Grande and the Sabine River, barrier-beach, lagoonal, and estuarine deposits are being formed. Dune sands and alluvial sands and clays have been deposited in large quantities in southwestern Texas during Recent time while southern Louisiana has been the site of delta, marsh, and alluvial-plain deposition. Contemporaneously marine sands, sandy shales, and shales are being deposited in the Gulf of Mexico.

Modern conditions of deposition are significant because they reflect conditions as they must have been many times during the Cenozoic era. Simple descriptions such as "delta deposits" or "alluvial plains" as applied to the entire non-marine part of a formation must be incorrect. Probably no Gulf Coast Tertiary formation is entirely deltaic; deposits of differing origins must combine to make up every formation.

The limited areal extent of the non-marine facies of Recent deposits in the large area between southern Louisiana and the dune area in southwestern Texas is noteworthy. Recent deposits are almost absent in this region a few miles back from the shore line. This shows that a thick marine deposit encountered in well sections may have no equivalent in the outcrop. It is the writer's thesis that this was the condition during upper *Heterostegina* and *Discorbis* time. The shore line during its maximum advance in late *Heterostegina* time was a very short distance north of Tomball. Continental deposition then, as now, was limited to a very narrow belt, and the Coastal Plain was being eroded in the area now occupied by the outcrop. Thus, a hiatus marks the equivalent position of upper *Heterostegina* and *Discorbis* strata in the outcrop as it does Recent strata a few miles inland from the present shore line.

Geologic History

PRE-TERTIARY

The pre-Tertiary history of the Coastal Plain in the vicinity of Harris County, Texas, is entirely conjectural. Deposits older than the Tertiary are beyond reach with present drilling methods, and conclusions on the early history of this area must, therefore, be based on evidence found farther inland where these older rocks have been penetrated by the drill or are exposed at the surface.

This region must have been a part of the Llanoria landmass during the Paleozoic era. The source of the deposits which filled the Ouachita geosyncline was a landmass toward the south, and as the buried

Ouachita structure now occupies approximately the position of the inner boundary of the Coastal Plain in Texas, the conclusion that the central and eastern parts of the Texas Coastal Plain was a part of that great, positive landmass seems unescapable. This is corroborated by the fact that a well in Guadalupe County, Texas, went directly out of Travis Peak (Trinity) beds into the crystalline basement. The Paleozoic history of this area until the time of the orogeny, then, was predominantly one of repeated uplift and almost continuous degradation.

The main streams flowed northward during Paleozoic time, bearing sediments which filled the geosyncline to a maximum depth of more than 25,000 feet.

The geologic history between the time of the Ouachita orogeny and the beginning of the Cretaceous period is obscure. Non-marine Triassic beds have been mapped in the Panhandle of Texas and in West Texas, and marine Jurassic beds crop out in Hudspeth County, but all of these beds are absent in the region of the Llano uplift, and in well sections in Guadalupe County. The Jurassic seas that deposited the beds in Hudspeth County came from the south, and although this sea may have transgressed over what is now the southern border of the Coastal Plain and yet not have reached the vicinity of Guadalupe County-and the Llano area, evidence to indicate that such was the fact is lacking.

AGE OF GULF COAST SALT DEPOSITS

Many salt plugs have pierced the older Coastal Plain sediments and arched the younger strata in parts of Texas, Louisiana, and Mississippi to form the well known Gulf Coast salt domes.

The age of the source beds for these salt plugs is unknown. Early speculation on this problem favored the assignment of the salt to the Permian chiefly because the great salt deposits of West Texas were known to be of that age. A large part of contemporary opinion still favors such a correlation. Spooner,[46] in concluding that the salt must have been deposited during Permian time, is impressed by events which he believes must have transpired after the uplift in early Permian time. He reasons that the elevation of the Ouachita Mountains must have been "concomitant with depression of Llanoria" in early Permian time. The Permian peneplanation of the mountainous region must then have been coincident with deposition in the region of old Llanoria. Spooner then concludes that

[46] W. C. Spooner, "Oil and Gas Geology of the Gulf Coastal Plain in Arkansas," *Arkansas Geol. Survey Bull. 2* (1935), pp. 20–21.

if the assumption of a Permian sedimentary basin is admitted, the salt in northern Louisiana and eastern Texas is most logically correlated with the Permian series.

Although this line of reasoning is a definite contribution toward the solution of this problem, the assumption of a Permian sedimentary basin here and the assumption that Permian deposition means salt deposition are not inevitable.

The presence of fossil algae in the salt at Markham dome, Matagorda County, Texas, which are believed to be identical with algae found elsewhere in the Permian was Powers'[47] basis for assigning the salt to the Permian. Schuchert questioned the reliability of algae as stratigraphic markers on the ground that they are poorly preserved and slowly evolving.

The alternative to the foregoing possibility is the assignment of the salt to a post-Permian-pre-Navarro age. Schuchert[48] is convinced on the basis of facies and faunal changes plus paleogeography, that Permian formations at the surface in central and western Texas can not extend under cover of the Cretaceous so far east as the present Gulf border, and he has on different occasions said that the salt probably comes from the older part of the Comanchean series.

Brown,[49] in a detailed article, which approaches the problem through a general study of the origin of salt deposits, paleogeography, and inclusions in cap rock, considers the Cretaceous age of these deposits proved although he assigns a different age to the salt in each of the several basins. Barton, in a review of Brown's paper, very logically questions the validity of Brown's criteria, pointing out in particular that inclusions of Navarro strata in the cap rock do not establish the Navarro age of the cap rock, but that they prove, instead, a pre-Navarro age. Barton[50] considers the age of the mother salt deposit unknown but believes that it must be at least as old as early Comanche because "Glen Rose has been brought up by the Boggy Creek dome, Anderson and Cherokee counties, Texas." He also points out that "basal Lower Cretaceous rests on the top of the salt at Smackover, Union County, Arkansas."

[47] Sidney Powers, "Interior Salt Domes of Texas," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 218.

[48] Charles Schuchert, *Historical Geology of the Antillean-Carribbean Region*, John Wiley and Sons, Inc. (1935), pp. 290–91.

[49] Levi S. Brown, "Age of Gulf Border Salt Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1227–96.

[50] Donald C. Barton, "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1045–50.

The Navarro inclusions aforementioned were found in the South Liberty dome which is a short distance east of Harris County. This proves that the salt in the gulf border area is pre-Navarro and the Glen Rose inclusions at Boggy Creek prove a pre-Glen Rose age for the salt of the interior basin. With only such inconclusive data on this problem, a solution is not now possible.

CRETACEOUS SEAS

Most of the epeiric seas had withdrawn from the continent by the end of the Jurassic, and the entire Texas Gulf Coast may have been above sea-level.

The Cretaceous seas advanced far inland, covering much of Texas. The minimum extent of the seas which deposited the several Comanche and Upper Cretaceous groups has been shown by Adkins.[51] The maximum advance of this period was during Austin time. The seas withdrew at the end of the Cretaceous period and have never since advanced so extensively over central North America.

These epeiric seas deposited large amounts of limestone and chalk together with arenaceous and argillaceous beds in the region now occupied by the western part of the Gulf Coastal Plain. That the seas withdrew at times and then readvanced is shown by the unconformities in the outcropping sections. Whether these regressions brought the shore line as far south as the outer border of the Coastal Plain or whether there was continuous deposition here throughout Cretaceous time is unknown.

CENOZOIC

In contrast to the Cretaceous seas, those of the Tertiary and Quaternary time did not advance far inland, and they oscillated frequently, resulting in a characteristic interfingering of marine and non-marine deposits.

The era opened with an advance of the sea over the Coastal Plain which lasted during all of Midway and earliest Wilcox time. The Kincaid formation at the outcrop rests unconformably on the Cretaceous, and its basal strata are near-shore, shallow-water deposits, recording the invasion of the sea over the previously eroded Cretaceous surface. The Wills Point strata at the outcrop were deposited in relatively deep water, but the Seguin formation is a shallow-water deposit, recording the beginning of the retreat of the sea. Formations above the Seguin of the Wilcox and Claiborne groups are alternately continental and marine at the surface, and the Jackson is part marine

[51] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, pp. 277 and 403.

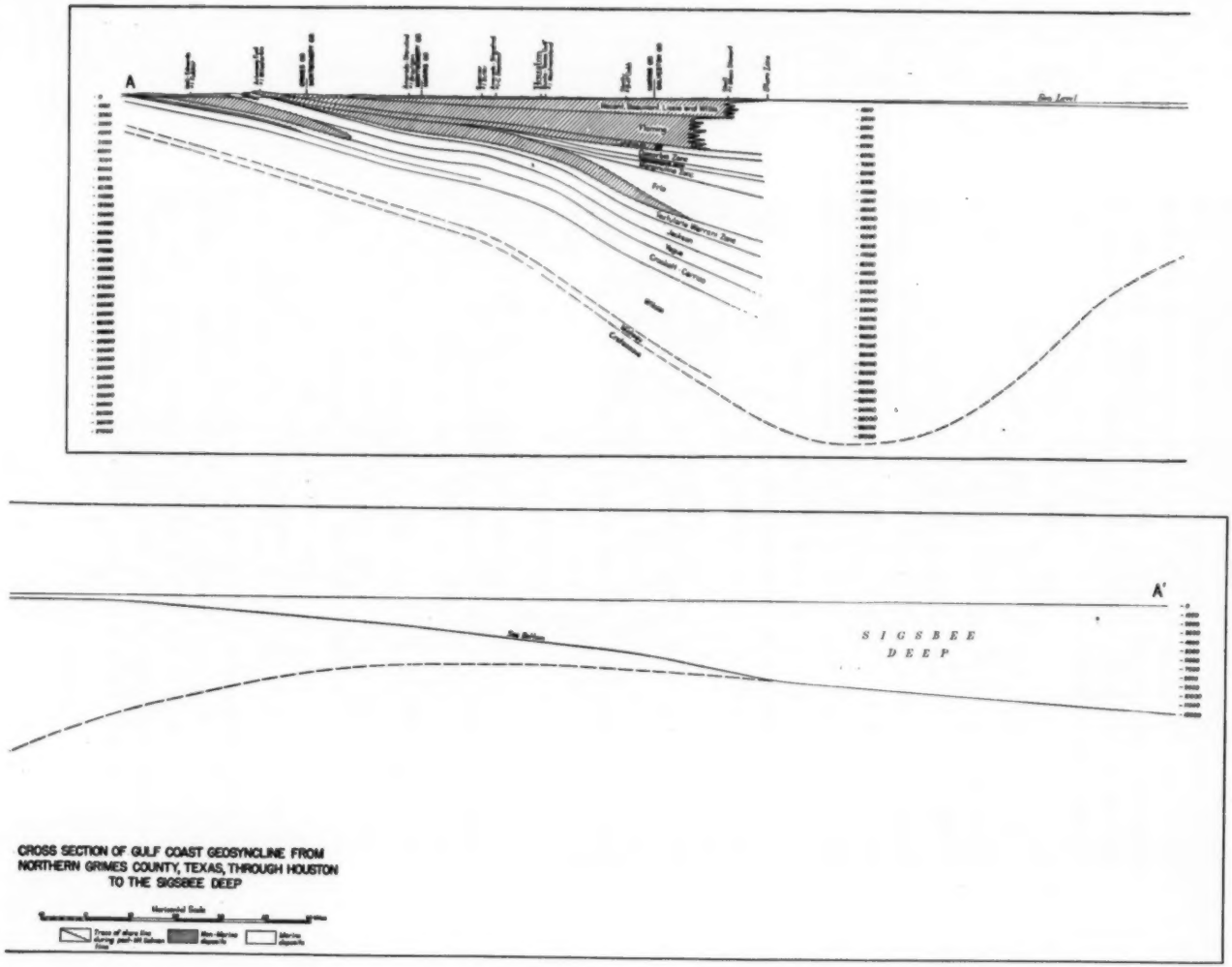

FIG. 8.—Cross section of Gulf Coast geosyncline.

and part non-marine. The remainder of the Cenozoic strata at the outcrop is continental, but deep wells in the vicinity of Harris County and other areas similarly located with respect to the present shore line show that many of these beds are marine there. The history of the Cenozoic seas is thus one of frequent oscillations and a gradual withdrawal in the latter part of the era. The detailed succession of paleogeographies, beginning with the Crockett, is given in the section on stratigraphy and illustrated in the series of paleogeographic maps.

GULF COAST GEOSYNCLINE

The aggregate thickness of these Tertiary and Quaternary strata shows that during Cenozoic time the area now occupied by Galveston and Brazoria counties, Texas, was depressed at least 30,000 feet and probably as much as 35,000 feet (Fig. 8). The area now occupied by Harris County was depressed somewhat less. The general process of down-warping was interrupted frequently by reversals of movement. These epochs of uplift were probably brief in comparison with the periods of sinking which is the dominant factor in the Cenozoic history of the Gulf Coast.

To explain this excessive sinking of the area along the coast by postulating a similar amount of sinking over the entire area of the Gulf of Mexico involves two serious difficulties. First, such excessive depressions of the earth's surface have been achieved in so short a time only in relatively long, narrow belts and do not involve areas of the magnitude and shape of the Gulf of Mexico basin. Such movements, in other words, are not epeirogenic but are the initial stage of an orogenic cycle. Second, if the entire Gulf of Mexico basin was depressed 30,000 feet, a block of sediments 20,000–25,000 feet thick, covering an area of 700,000 square miles would be required to fill the Gulf to its present mean level. Much of this would have to come from the basins of the Mississippi River and adjacent smaller streams. These streams would have had to furnish a wedge of sediments more than 30,000 feet thick at the coast and more than 18,000 feet thick in the region of the Sigsbee Deep. This seems unlikely in view of the fact that deposition instead of erosion occurred over much of the Great Plains and in the lower Mississippi valley during Tertiary time.

That formational thickening increases markedly within 50 miles of the present shore line has been shown previously. Dips in southern Harris County and in Galveston and Matagorda counties are much greater than in northern Harris County and in Montgomery County. These excessively steep dips are found not only in this area but in a long belt adjacent to the shore line in eastern Texas and Louisiana.

FIG. 8.—Cross section of Gulf Coast geosyncline.

This sudden increase in the regional dip together with the excessive thickness of the Tertiary sediments indicates the presence of a geosyncline of major dimensions with its axis essentially parallel with the shore of the Gulf of Mexico. Geophysical evidence of the existence of this great geosyncline has been presented by Barton, Ritz, and Hickey.[52] In this important paper, the authors give indubitable geophysical evidence of this geosyncline, the axis of which they place approximately at the site of the present shore line.

Although the western limit of this structure is unknown, isopach maps show a distinct thinning of some of the formations in the longitude of Matagorda and Wharton counties, Texas, and subsurface structural maps show a gulfward component to the strike at about the same place. Although there is thus some reason to believe that the structure becomes less pronounced west of Matagorda County, the possibility that it does continue southwestward but with gentler dips or that the axis diverges from the present shore must be considered. It is also possible that this formational thinning reflects only a northwest-striking, anticlinal ridge.

Recent studies of the Gulf Coast geosyncline in Louisiana have been made by Howe,[53] Russell,[54] McGuirt, and Moresi.[55] Howe estimates the maximum thickness of the Cenozoic in southern Louisiana to be approximately 31,000 feet.

The picture of the structure paralleling the coast is complicated by the north-striking Mississippi embayment and by other much smaller north-striking synclines and anticlines. The exact relationship of the Gulf Coast geosyncline to the Mississippi embayment is yet to be determined.

The Cenozoic history of this part of the Gulf Coast is largely the pouring of sediment into this sinking trough. Both the sinking and the sedimentation were interrupted for relatively brief periods of time by reversals of movement which exposed to erosion the region now occupied by the Gulf Coast.

ORIGIN OF GEOSYNCLINAL DEPRESSION

Geosynclines are sediment-filled, generally elongate depressions in the earth's surface. They may come into existence in one of two

[52] Donald C. Barton, C. H. Ritz, and Maude Hickey, "Gulf Coast Geosyncline," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1446–58.

[53] Henry V. Howe, "Louisiana Petroleum Stratigraphy," *Louisiana Dept. Conserv. Bull. 27* (1936).

[54] Richard Joel Russell, "Physiography of Lower Mississippi River Delta," *ibid.*, *Bull. 8* (1936).

[55] See bibliography in *Louisiana Dept. Conserv. Bull. 27* for papers by McGuirt, Moresi, and previous papers by Howe.

ways. Either the surface was depressed by the weight of accumulating sediments, or its lowering is due to independent forces arising beneath the surface. The one hypothesis places the cause on the earth's surface; the other places the cause beneath the earth's surface. The one accounts for the pattern of the mobile belts in the fortuitous wanderings of the major streams; the other accounts for the pattern of the mobile belts in the manner of crustal yielding to stresses which are caused by forces originating in the subcrustal part of the earth.

The postulation that geosynclinal depression is due to sedimentary loading has found many champions in the past and present. Russell[56] gives a historical review of contributions on this problem. He himself attributes the sinking of the Gulf Coast geosyncline to this cause. Other proponents of the theory are Howe,[57] and to a less extent, Barton, Ritz, and Hickey.[58]

The case for this theory rests largely on the observation that much of the sediment in the Gulf Coast geosyncline accumulated near sea-level, that maximum subsidence is at the site of the great deltas, that the mean of observed gravity readings on the Mississippi delta is almost zero, and on the belief that the theory of isostasy supports it.

The proponents of this theory contend that the deposition of thousands of feet of Tertiary and Quaternary strata under nearly sea-level conditions proves that the rate of subsidence is a function of the rate of sedimentation. The subsidence must, therefore, be a result of the sedimentation for it would be highly improbable that the effects of two unrelated factors, such as the rate at which streams brought down sediment to the site of the geosyncline and forces arisin the earth's interior, would proceed at the same rate. Russell[59] states that it would be

> a miracle that sedimentation should occur at a rate just sufficient to deposit all materials filling the trough neither far above nor far below sea-level.

Miocene, Pliocene, and Pleistocene deposits are thicker in the Mississippi delta region than anywhere else in the Gulf Coast, and some geologists take this to mean that the great weight of these deposits caused the increased depression which is found here. Furthermore, the lack of an observed gravity anomaly is considered to indicate a compensated column which means that a mass of rock

[56] Richard Joel Russell, *op. cit.*, pp. 180–93.

[57] Henry V. Howe, *op. cit.*

[58] Donald C. Barton, C. H. Ritz, and Maude Hickey, *op. cit.*

[59] Richard Joel Russell, *op. cit.*, p. 180.

below, equal to the mass of sediment deposited above, has been removed. If this is true, then causal relationship is inferred.

Finally, some proponents of the sedimentary-load hypothesis assume the validity of the theory of isostasy and maintain that their hypothesis is a valid deduction from the general case to the particular.

Indeed, a beautifully simple explanation of geosynclinal deformation appears to be supported by these arguments, and the idea has proved to be attractive to most writers on the Gulf Coast geosyncline. But before accepting this theory, a more critical examination of the arguments supporting it should be made as well as a consideration of alternative hypotheses.

The presence of tens of thousands of feet of sediment in the geosyncline, all deposited approximately at sea-level, is a fact of prime importance. If this means that the volume of sediment brought to the site of the Gulf Coast geosyncline during any interval of time just equals the increase in the volume of the geosynclinal trough during that same interval of time, then a weighty argument has indeed been advanced to support the idea that deformation is caused by the weight of the sediment. It is highly improbable that tensional stresses in the crust or other forces below the earth's surface just happened to cause a rate of subsidence exactly sufficient to accommodate all the sediment being brought down by the streams. However, the assumption that sea-level deposition in the geosyncline means that the rate at which sediment is transported to this area equals the rate of depression rests on a failure to consider all possibilities. The rate of sedimentary accumulation along the Gulf border and in the margin of the Gulf of Mexico may be less than the rate of geosynclinal depression, it may equal the rate of geosynclinal depression, or it may exceed the rate of geosynclinal depression. The first case would, of course, result in deep-water deposition. Eocene beds in the geosyncline may be deep-water deposits, but most of the post-Vicksburg beds were surely deposited near sea-level or wave-base. The second case would result in near sea-level deposition, and proponents of the sedimentary-load theory conclude, therefore, that the shallow-water deposits in the geosyncline indicate that geosynclinal depression did necessarily proceed at the same rate as the transportation of sediment to the Gulf of Mexico. A consideration of the third possibility, however, shows the fallacy of this conclusion. If sediment was brought to the Gulf of Mexico faster than the rate of geosynclinal depression, then the trough would be filled to sea-level or wave-base, depending on the exact position of the strand line with respect to the geosyncline, and the excess load would be carried by wave action and cur-

rents beyond the geosyncline as it borders on an open basin. Under these conditions, then, nearly sea-level deposition would occur in the structural trough and the appearance of the stratigraphic column would be the same as though the volume of sediment brought down at any particular interval of time did equal the increase in the volume of the trough during that same interval of time.

The large amount of sand in the marine, post-*Heterostegina* formations at the present shore line indicates that sediment was bypassed beyond the axis of the trough. Furthermore, the gentle slope of the sea floor south of the geosyncline suggests a depositional surface as far as the 50-fathom line which, in places, is 130 miles south of the supposed position of the axis of the geosyncline. The fact that salt domes as elevated topographic features on the sea floor are largely, if not entirely, absent from this gentle slope, but are conspicuously present beyond it, is best explained by assuming that they have been covered by recent sediment or truncated by wave and current action. This substantiates the interpretation of this gentle slope as a depositional surface. Good reason thus exists for believing that a greater volume of sediment was transported to the gulf shore line during Tertiary time than the geosyncline proper could hold and that the excess was carried by waves and currents beyond the geosyncline into the open basin of the Gulf of Mexico. The conclusion that nearly sea-level deposition of large amounts of sediment in the geosyncline indicates that geosynclinal depression proceeded at the same rate as the transportation of sediment to the site of the geosyncline is, therefore, not justified.

This condition of an excess of sediment existed in other geosynclines. The Appalachian geosyncline was not able to accommodate all the sediment brought to it during the Paleozoic era. The Paleozoic clastic sediments in the area now occupied by the states west of the Appalachian Mountains represent the excess eroded from old Appalachia and carried seaward beyond the geosyncline. If the weight of accumulating sediment could cause deformation, there would be no deposition of coarse clastic sediments seaward from the structural trough. This fact itself refutes the main argument frequently advanced by proponents of the sedimentary-load theory.

The fact that Miocene, Pliocene, and Pleistocene deposits are thickest in the Mississippi delta region does not require, as proponents of the sedimentary-load theory contend, that the superior weight of this great body of sediment caused the excessive subsidence. Equally possible is the opposite—that the Mississippi River and the delta got their positions as a result of excessive subsidence. The thick

sedimentary accumulation could, therefore, be the result of downwarping rather than the cause of it.

The fact that geophysical investigations have shown that the observed gravity anomaly on the delta is almost zero is very impressive until allowance is made for variations in surface densities. Bucher[60] has shown the important influence of abnormal densities close to the surface on observed values of gravity. He points out that

> since gravitative attraction varies inversely as the square of the distance, a heavy rock mass immediately beneath a station will register an excess of gravity over that of surrounding crustal columns of equal elevation and equal mean density.

A light rock mass at the surface will, of course, have the opposite effect on the observed gravity values.

This effect of variations in rock density upon observed gravity values has been recognized, as Bucher observes, by geologists and geodesists for some time, and it must not be ignored in the interpretation of observed values. The gravity readings on the Mississippi delta must be considered in the light of this fact.

In discussing the Mississippi delta, Bucher[61] states that

> if the column beneath the delta were in isostatic equilibrium, the light, unconsolidated sediments of at least the upper part of the delta should register a strong negative anomaly. . . . If the delta constituted a local, essentially equidimensional body, the absence of such strong negative anomalies would mean that there is an excess of mass below, that is, the crust is not in equilibrium and that the delta constitutes an excess load. If, on the other hand, its shape approached that of a thin sheet of large horizontal dimensions, its differential effect on the value of gravity would be negligible.

The fact that the Mississippi delta has a great thickness is admitted by proponents of the sedimentary-load theory. As the observed gravity readings approach zero (−0.005 dyne),[62] it appears that the whole column which includes the Mississippi delta is not compensated for. The sedimentary-load theory, however, requires near-compensation at all times. Subcrustal movement and subsidence must keep pace with sedimentation. Failure to do so would result in a progressive, seaward movement of the shore line and no localization of sedimentation through long periods of time would result. The fact that the Mississippi River has built out its delta as far as 100 miles south of the position of the shore line on the east and west shows

[60] Walter H. Bucher, *Deformation of the Earth's Crust*, Princeton University Press (1933), pp. 30–33.

[61] Walter H. Bucher, *op. cit.*, p. 33.

[62] *Ibid.*, p. 33.

clearly that subsidence has not recently kept pace with sedimentation. Gravity studies on the Mississippi delta, therefore, do not support the idea that the weight of accumulating sediments causes the depression of the geosynclinal trough.

Some geologists believe that the sedimentary-load theory is necessarily a consequence of the theory of isostasy. The reality of isostatic changes is not questioned here. The controversy about isostasy is the extent to which the deformation of the earth's crust can be attributed to it.

That the mechanism of sedimentary loading as the cause of deformation requires almost perfect compensation at all times is conceded by proponents of this theory.[63] But such a mechanism is predicated on a lack of inherent strength in the crust of the earth. Even geodesists concede that the crust is able to bear an excess load of 600 feet of rock before failing. Geologic data indicate that this load is likely to be measured in thousands of feet rather than hundreds.[64] Russell[65] points to the subsidence of the continent under the weight of an ice cap as direct evidence that a superficial load causes crustal subsidence. However, the depression of the crust in a long, narrow belt for tens of thousands of feet can not be compared with the relatively slight subsidence of the nearly equidimensional, glaciated regions. The spreading of the ice over large areas on the continent rather than its depression of the crust along deep, narrow troughs adjacent to the focal points of the glacier is evidence against the thesis that subsidence is the effect of sedimentation.

Although isostasy can restore equilibrium, there is no evidence to show that it can effect the reverse. Where equilibrium has been established and the geosyncline has been filled to sea-level, the site of deposition should change. This is not the case in the Gulf Coast geosyncline for depression has been localized in this one place throughout most, if not all, of Tertiary time.

Difficulties with the sedimentary-load theory are not limited to the failure of the arguments intended to support it; there are at least three other facts which are not compatible with the theory. First, if the weight of accumulating sediments causes down-warping, the maximum thickness of a formation which has both a marine and a non-marine facies should be at the shore line of that formation. A substantial part of the Tertiary formations reach their maximum thickness far south of the shore line of that time. Second, the sedimentary-load

[63] Richard Joel Russell, *op. cit.*, p. 184.

[64] Walter H. Bucher, *op. cit.*, pp. 34–35.

[65] Richard Joel Russell, *op. cit.*, p. 189.

theory does not account for the reversals of movement evident during Tertiary and Quaternary time. Third, this theory does not account for the oceanic deeps which offer problems concerning their origin similar to those involved in the origin of sediment-filled geosynclines.

Formational thickening as far south as Bammel in north-central Harris County has been proved for formations at least as old as the Cook Mountain and probably for the rest of the Claiborne group also, depending, as stated previously, on the age of the lowest sand encountered in this well. Pre-Yegua formations of the Claiborne group are alternately marine and non-marine at the outcrop, the shore line having been north of that area part of the time and south of it part of the time. In the Bammel area 75 miles south, these formations are all marine shales or slightly sandy marine shales, and they are thicker there than at the outcrop near the shore line of that time. Yegua beds are 1,200–1,240 feet thick in northern Montgomery County which is the average position of the shore line during Yegua time. In central Harris County, 50 miles from the shore line, the Yegua is more than 1,400 feet thick. The average position of the shore line for the Jackson is at the outcrop or a short distance landward. The Jackson is approximately 900 feet thick there but it is 1,380 feet thick in southwestern Harris County 80 miles from the old shore line. The sea retreated throughout the deposition of the *Textularia warreni* beds and their exact continental equivalent is not definitely known. The shore line during Frio time was in the geosyncline. The *Marginulina*, *Heterostegina*, and *Discorbis* zones were deposited in a transgressive-regressive sea and there probably is no continental equivalent of the upper part of these beds. The Catahoula shore line was in the geosyncline but the Catahoula does not thicken appreciably toward it; the thickness of this formation remains nearly constant. The shore line for Fleming and post-Fleming deposits was in the geosyncline. Thus, for all post-Wilcox formations, there seems to be no relation between formational thickening and paleogeography.

A yet more striking case than this of lack of relationship between shore lines and maximum subsidence is the Wichita geosyncline of Oklahoma. This geosyncline was located far from either the landmass of Llanoria on the south or the Canadian shield on the north. Though Howe and Russell[66] confidently believe "that drainage patterns determine future courses of mountains," early Paleozoic drainage patterns had nothing whatever to do with determining the position of the Arbuckle, Wichita, and Amarillo mountains.

The mechanism pictured by the sedimentary-load theory can not

[66] *Ibid.*, p. 193.

account for the epochs of uplift in areas where subsidence and sedimentation have been the general rule. The history of all geosynclines has been marked by relatively short periods of uplift during the initial stage of the orogenic cycle when down-warping was predominant. That this is also true of the Gulf Coast geosyncline and the Gulf Coast in general is shown by unconformities in the section, by fluctuations in the shore line, by the presence of submarine canyons in the Gulf of Mexico, and by the elevated beach at Corpus Christi. The unconformities in the section and the succession of paleogeographies have been treated elsewhere in this paper. Notable retreats of the sea occurred just after the close of the Jackson and during upper *Heterostegina* and *Discorbis* time. The basal Catahoula contact is marked by a major unconformity and the region occupied by the geosyncline must have been uplifted considerably. Recent uplift is shown by the entrenched streams found everywhere on the coast. Streams in northern Harris County are entrenched as much as 85 feet. The paleogeographic studies of Moody[67] in Louisiana show that the shore line there fluctuated hundreds of miles and must indicate reversals of movement of hundreds of feet.

The submarine canyon south of the mouth of the Mississippi River is evidence of uplift. Shepard[68] relates this trough to eustatic changes in sea-level due to glaciation and deglaciation and subsequent subsidence of the region, but the relief of the canyon is too great to be accounted for in this way. A cross section drawn where the 2,400-foot contour crosses the bottom of the canyon shows more than 1,800 feet of relief. Shepard accounts for the flat bottom of this trough by mud fill, pointing out that the profile slope is the same as the angle of repose for mud. A projection of the slope of the canyon walls shows that the bottom of the canyon must have been at least 600 feet below the present level of the mud. This gives a relief of 2,400 feet for the canyon at this point. Farther south the relief was probably greater. If this is to be accounted for by changes in sea-level due to glaciation, a lowering of sea-level of more than 2,400 feet is required. As the oceanic areas are 2.6 times the land areas and as only a small fraction of the land areas not now covered by glaciers was covered by Pleistocene ice sheets at any one time, it is obvious that the average thickness of the ice sheets would have to be many times 2,400 feet to cause the erosion of the submarine canyon south of the mouth of the

[67] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 531–51.

[68] Francis P. Shepard, "Salt Domes Related to Mississippi Submarine Trough," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 1349–62.

Mississippi River. A thickness many times greater than that indicated by present ice sheets and by physiographic observations in the northern mountain regions would be required. An appeal to uplift of the geosynclinal area seems inevitable.

These epochs of reversal of movement in the geosyncline, indicated by unconformities, shore-line migrations, entrenched streams, the submarine canyon, and the elevated beach at Corpus Christi, are opposed to the basic tenets of the sedimentary-load theory.

An obvious argument against this theory is that many structural troughs could not have been caused by the weight of accumulating sediments because they contain no sediment. These, of course, are the ocean deeps.

It is interesting to note that Russell,[69] in looking to "the great laboratory of Nature" which he recommends in preference to the "lesser laboratories of man," appealed to the relatively slight continental subsidence under the weight of an ice sheet when he could have utilized the Sigsbee Deep which is much more comparable with the Gulf Coast geosyncline in shape, amount of subsidence, and geographic position. In fact, the Sigsbee Deep and the Gulf Coast geosyncline may be cognate structures. On the south side of the Sigsbee Deep, the slope is more than 11,000 feet in less than 50 miles. Yet there is no sedimentary load to depress this structure. Obviously the theory fails in this case and has to be limited to structures filled with sediment. The fact that a structural trough is or is not filled with sediment depends only on its geographic setting and there is no reason to suppose that different causes must be attributed to the formation of each. If one has to appeal to a different cause for the oceanic deeps, a cause that could also account for all the types of geosynclines, then the case in favor of that theory is strong.

In view of the failure of the sedimentary-load theory to account for the observed facts and the apparent absence of any other cause on the earth's surface, a cause of geosynclinal depression must be sought beneath the surface.

Many hypotheses have been formulated concerning the nature of the processes below the earth's surface which lead to the formation of geosynclines. Here again two alternatives exist. Either geosynclines arise as concomitant features more or less simultaneously with the formation of folded mountains in the course of a continuous process of crustal deformation, or they come into existence independently, through a set of forces different from and possibly opposed to those which cause the folding of mountains. Most geologists favor the

[69] Richard Joel Russell, *op. cit.*, p. 189.

former view. But the presence of so conspicuous a geosyncline as that here discussed without a corresponding "welt"[70] of mountains adjoining it, seems to the writer to be convincing proof that not all geosynclines, and certainly not this one, have formed as a by-product of the process which raises welts.

Of attempts to account for the presence of geosynclines independently of welts and folded mountains, the writer wishes to mention two which follow radically different lines.

Geosynclines form on the margins of earth "blisters" according to Rich,[71] which result from local subcrustal heating possibly due to local excess of radioactive matter. Isostasy comes into play when erosion removes the top from the high area (in the Gulf Coast geosyncline, presumably the adjoining part of the continent). Geosynlines result from the local withdrawal of subcrustal matter at depth from the foreland toward the high land to restore isostatic equilibrium.

If there were little or no friction in the flow of subcrustal matter, the withdrawal of matter from beneath the vast foreland would be distributed over its whole area. But because of the very large internal friction which opposes movement, material is withdrawn at first only nearest the point of deficiency of mass, that is, along the edge of the "blister." If no sediment accumulated in it, the depression would gradually vanish as surface equilibrium is established by the sluggish flow of the viscous subcrustal matter. But when sediment fills the trough, it is perpetuated and its sinking even accentuated while it forms.

Bucher, on the other hand, points out that geosynclines deepen during "anorogenic" times, that is, during those epochs of the earth's history when relief on the earth's surface dwindles to a minimum and when the seas transgress widely over the continents; whereas they tend to shallow or even emerge completely during "orogenic" times, that is, when relief on the earth's surface increases and mountain folding is active. From this contrast he infers that geosynclines result from forces opposed to those which make mountains. If the latter are due to compression in the earth's crust, geosynclines should be the result of tensional stresses in the crust, comparable with the hollows formed on an inhomogeneous rubber sheet under tension, which stretches and thins most at the weakest points. This hypothesis

[70] Walter H. Bucher, *op. cit.*, pp. 4–5.

[71] John L. Rich, "A Mechanism for the Initiation of Geosynclines and Geo-Basins," abstracts of papers offered at the fiftieth annual meeting of the Geological Society of America, 1937.

accounts equally well for geosynclines on ocean floors, as for those on the continental platforms, and for reversals in movement, so characteristic of geosynclines. According to it, the depressions localize the drainage of the land and the deltas. The fact that many formations involved in the Gulf Coast geosyncline attain their maximum thickness far seaward from the shore line offers no difficulty to it.

This hypothesis requires essential simultaneity of all major epochs of geosynclinal and of orogenic phases over the whole earth, which is at present difficult, if not impossible, to prove. Furthermore, no plausible cause has been suggested for the alternation of compression and tension in the crust. These seem to be the chief difficulties of this hypothesis.

Studies of the Gulf Coast geosyncline do not appear to the writer, at present, to justify the final acceptance of any of the hypotheses for the origin of geosynclines thus far advanced. Sufficient evidence does exist, however, to justify the abandonment of those hypotheses which require the formation of folded mountains or welts concomitant with geosynclines, and critical evidence opposed to the sedimentary-load theory also appears to exist. The more promising field of speculation is to be found in those forces which arise within or beneath the earth's crust rather than in forces of a surficial origin. Furthermore, any hypothesis of world-wide application must account for geosynclines which are formed independently of excessively high elevations as well as those which are associated with such elevations.

Whatever may be the primary cause of the formation of the Gulf Coast geosyncline, isostatic adjustment to the weight of accumulating sediments may have been an important secondary factor. The Sigsbee Deep suggests the possibility that the Gulf Coast geosyncline was a similar structural and topographic basin in early Tertiary time when the strand line was far inland. After this basin had come into existence, it offered an opportunity for the accumulation of thousands of feet of sediment. The weight of the first several thousand feet of Tertiary deposits may have been sufficient to overcome the inherent strength of the crust and to cause further sinking. This phase in the evolution of the Gulf Coast geosyncline could not have extended later than Vicksburg time because Frio deposits in the geosyncline were deposited near sea-level, and henceforth there was probably no opportunity for the accumulation of a sufficient excess of mass to overcome the inherent strength of the crust. From this time on, the forces acting within or beneath the crust must have been the sole cause of deformation.

It is to be emphasized that with such a history of this structure as

outlined in the foregoing paragraphs, the writer assumes that at first there was a mass deficiency and that compensation was reached by the beginning of Frio time, that is, when nearly sea-level deposition occurred. This assumption is based on the belief that pre-Frio deposits in the geosyncline are of the deep-water type. This condition is suggested but not proved by paleogeographic data already given.

Physiographic History

Two physiographically distinct areas are present in the margin of the western Gulf Coastal Plain. One is an embayed area adjacent to the shore line, and the other is an entrenched area located farther inland. The embayed area is limited to a very narrow belt and has an excessively gentle slope. The profile from the shore line to northern Harris County indicates a physiographic unconformity about 50 miles from the shore line. The slope from Galveston to Houston, a distance of 50 miles, is 1 foot per mile. The slope from the 50-foot contour to the base of the Hockley scarp, a distance of 25 miles, is 4.6 feet per mile, and in northwestern Harris County elevations as high as 275 feet are recorded. In the area north of the 50-foot contour, streams are actively downcutting, whereas the area south of the line is embayed. Streams are entrenched all the way to the estuaries and in many places are slightly entrenched in the areas between the bays.

Recent uplift is shown by these entrenched streams present everywhere on the Texas Gulf Coast. In northern Harris County Spring Creek is entrenched 85 feet, and most of the streams in the vicinity of Harris County are entrenched 25–75 feet. The profile thus described shows that the uplift was greater north of the 50-foot contour than south of it.

The many drowned valleys and long tidal areas which mark the outer margin of the Coastal Plain have commonly been interpreted as the result of subsidence. Walter H. Bucher has suggested to the writer, however, that the drowning of the valleys may be the result solely of a rise of sea-level due to the deglaciations of the last 20,000 years. He points out that drowning is a universal phenomenon except in those regions where recently lifted terraces demonstrate that the land has been rising faster than the sea-level.

The profile of the present surface appears to support the latter hypothesis. As stated previously, the slope is very gentle south of Houston and is relatively steep north of there. This is the exact opposite of the curve described by the dip of the Tertiary beds which is steepest between Houston and the shore line and is gentlest northward from Houston. As the dip of the Tertiary beds is definitely the

curve for geosynclinal sinking, one would not expect that the mirror image of this curve, which is the present land slope, would also be the result of geosynclinal sinking. If the present land slope were the result of geosynclinal depression, the axis would have to be situated at least 50 miles north of the axis of deformation during Tertiary and Quaternary time. This is highly improbable. The present slope seems to be best explained by upward deformation along an axis north of the 50-foot contour. Such an uplift together with deglaciation explains the present profile, the entrenched streams, the estuaries, and also such an anomaly as the elevated beach at Corpus Christi. The slightly entrenched streams near the shore line are the result of a relatively small amount of uplift. They are not drowned because they have not cut down as far as the main streams which form the estuaries.

If this is the recent history of the Gulf Coast, then the submerged canyon south of the mouth of the Mississippi River and the present alluvium-filled canyon of the Mississippi were formed in a cycle of uplift and subsidence which antedates the uplift represented by the entrenched streams in Texas.

SIGNIFICANCE OF BARRIER BEACHES

The coast of Texas is bordered with barrier beaches. Padre Island and Matagorda Island are excellent examples. Behind these barrier beaches are equally well developed estuaries.

Russell[72] states that many geologists believe the Texas coast to be emergent because of the presence of these barrier beaches. He says that the use of barrier beaches as a criterion of coastal emergence "has had such impressive sponsorship that today most geologists accept it without question." Although this statement is debatable, he is correct in concluding that barrier beaches are not necessarily indicative of an emergent shore line. Russell's treatment of the barrier-beach problem, however, is noteworthy for its failure to show the significance of these topographic features.

N. M. Fenneman first pointed out to the writer that barrier beaches are a device to correct an excessively flat off-shore profile. Just as streams build up or cut down their bed to establish grade so there is an off-shore profile of equilibrium toward which waves and currents will direct their energy. If this slope from shore line to wave base is too steep, a cut-and-built-terrace will be formed to correct this deviation from the profile of equilibrium. If the slope is too gentle, the waves will expend their energy in dragging over this excessively flat surface and break before reaching the shore. An off-shore bar, or

[72] Richard Joel Russell, *op. cit.*, pp. 162–74.

barrier beach, will be formed at the line of breakers. The lagoon will soon be filled, and the barrier beach will then represent the new shore line. In this way the shore line will be moved seaward, the off-shore slope increased, and the profile of equilibrium established.

After a new cycle is inaugurated, then, the presence or absence of barrier beaches depends on the slope of the initial off-shore profile and not on the condition of emergence or submergence. Where a gently sloping surface like the Texas Coastal Plain is subsiding or where sea-level is rising upon such a surface, an excessively flat off-shore profile may be inherited since the slope from the shore line northward to the 50-foot contour is much less than from the shore line southward to the 100-fathom line. Barrier beaches and estuaries would then be formed simultaneously.

Russell[73] has proposed that a classification of shore lines on the basis of advance and retreat be substituted for the basis of submergence and emergence. The inadequacy of this proposal is apparent when one considers that a shore line can not advance appreciably without subsidence once the profile of equilibrium is established. When the profile of equilibrium is established, the energy of the waves is exhausted just as they reach the shore and they are without ability to attack the continent. Most of the features which mark the progressive changes incident to the evolution of a shore line are directly or indirectly a result of an off-shore profile which is not in equilibrium. As only diastrophism can substantially alter an off-shore profile once it is in equilibrium, the classification of shore lines on a basis of submergence and emergence has more real significance than a classification on a basis of advance and retreat.

[73] *Ibid.*, p. 174.

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VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 212-219, 1 FIG.

GEOLOGIC ASPECTS OF HEAVING SHALE IN TEXAS COASTAL PLAIN[1]

J. M. FROST, III[2]
Houston, Texas

ABSTRACT

After a thorough search for all fields and wildcat wells where heaving shale has been recorded in the Texas Coastal Plain, it has been found that there are five principal heaving-shale zones: Lower Miocene, Middle Oligocene, Vicksburg, Jackson, and Yegua. These formations form belts or trends parallel with the shore line of the Gulf of Mexico. The downdip limit of each trend can not be determined as accurately as the updip limit because of the less advanced drilling practices in the past, and because sufficient deep wells drilled downdip are lacking. A map showing the several trends is helpful in determining the probability of encountering heaving shale. A comprehensive bibliography is included.

For many years heaving shale has been of utmost interest because it is the only apparent reason why some of a certain group of structures can not be explored successfully. The problem of heaving shale is one of the most costly in the drilling of oil wells. Many of the ramifications of the problem have been the subjects of research but the geologic aspects have been studied less thoroughly. Very little work has been published concerning the geologic phase of heaving shale, and the writer hopes to contribute some information in this respect.

Considerable time was spent searching drilling records and various files in order to obtain data for this study. In the Gulf Coastal Plain between the Sabine River and the southwestern border of Jackson and Lavaca counties, all wells that reported heaving shale were considered. In the Gulf Coastal Plain between the southwestern border of Jackson and Lavaca counties and the Rio Grande, all wells that reported heaving shale and all wells deeper than 7,000 feet were considered. All wells below this depth were considered in order to prevent the possible omission of wells that would reveal data on heaving shale, particularly in the various zones known to have heaved in other localities. When a well of interest was found and more detailed information had to be obtained, the writer visited the company that drilled the well and secured such information as was needed. Research included all wells drilled prior to March 1, 1938.

Although these data were assembled for the purpose of studying the stratigraphic position, distribution, and geologic significance of heaving shale, there were no preconceived conclusions which had to

[1] Read before the Association at New Orleans, March 17, 1938. Manuscript received, June 6, 1938.

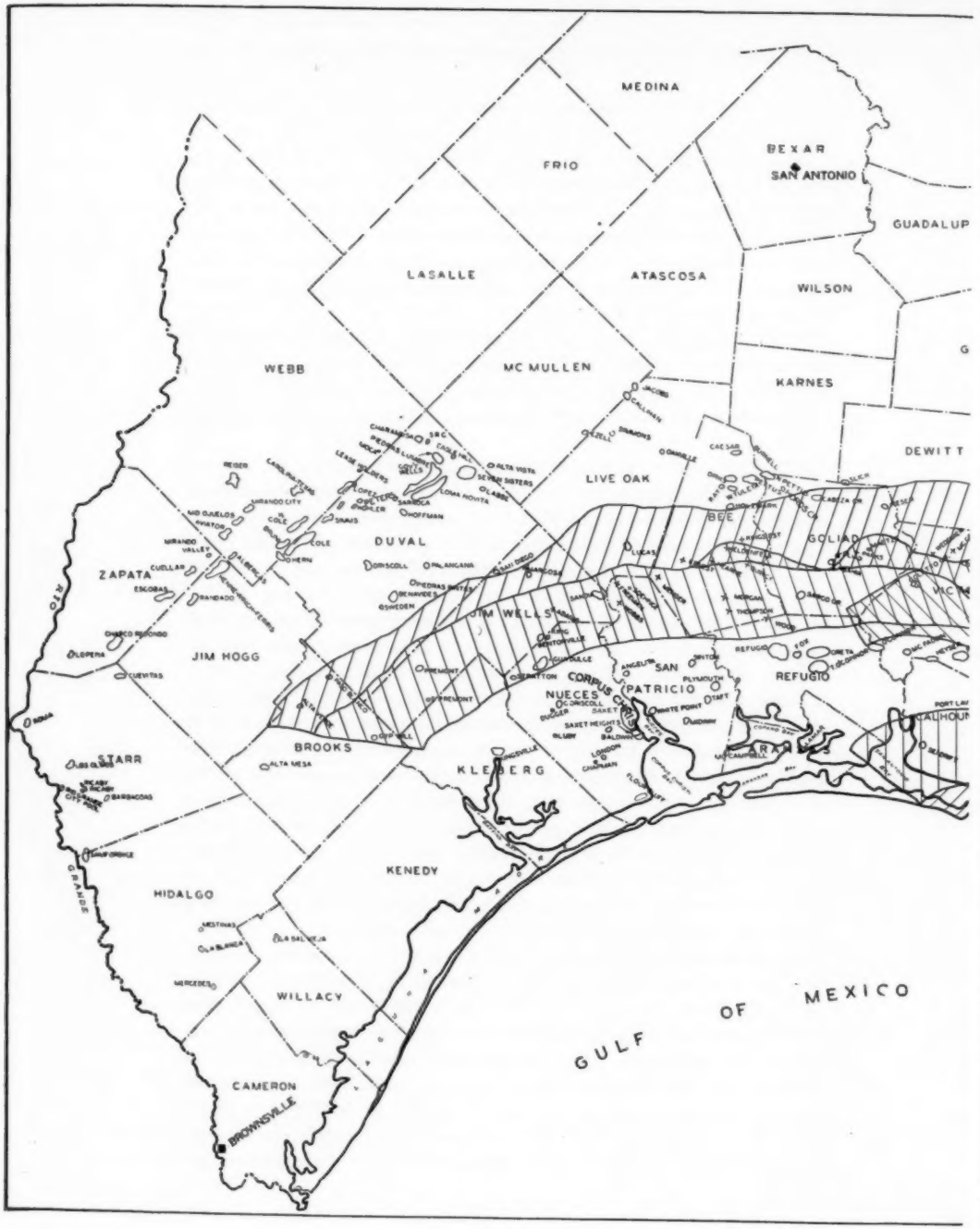
[2] Department of Geology, The University of Texas, Austin, Texas.

be proved; therefore, the results are without prejudice. It was found that there are five groups into which heaving-shale wells may be divided: those heaving in the Lower Miocene, the Middle Oligocene, the Vicksburg, the Jackson, and the Yegua formations. That part of the geologic column included under each group is indicated in the legend in Figure 1. These five groups include most of the heaving-shale wells; however, a few wells are reported to have heaved in the Frio formation. The groups form belts or trends across the Texas Coastal Plain, as indicated in Figure 1.

The trends that have been determined have approximately the same width, are parallel with the present shore line of the Gulf of Mexico, and extend along a large part of the Gulf Coast. All the heaving shale encountered is in the Oligocene, or a little above it, or slightly below it.

The fields and wells used to determine the various trends are listed in Table I which includes all places where heaving shale has been reported. In assembling the data on heaving-shale wells there were many hindrances. The recognition and classification of heaving-shale wells have changed. It was necessary to consider the date on which a well was drilled, because of the improved methods of drilling and improved equipment of recent years; wells have been drilled through shales in some areas where wells had been abandoned in previous attempts. A study of one well revealed pertinent information whereas another well did not, although the wells were so close that a perceptible variation was improbable. Many companies do not draw a distinction between heaving shale and caving shale because the distinction would be based more or less on personal interpretation. In the practice of some companies, if a formation could be penetrated it was not reported as heaving shale, but if the company was forced to stop drilling because of shale heaving in the hole, it was reported that the hole was abandoned due to heaving shale. Thus it can be seen that there are many elements which hinder a study of heaving shale even after sources of information are available.

Each field or well that had heaving shale was located on the map. The limits of each trend were determined by drawing lines to include all places where heaving shale of a particular zone was found. The two limits of each trend were not drawn with the same degree of certainty. The updip limit is up the regional dip, inland from the Gulf of Mexico, and the downdip limit is nearer the gulf. Because of the regional dip and because of the limited depths of drilling, the updip limit has been explored more fully and is more accurately placed. The downdip limit is subject to variation as more deep tests produce more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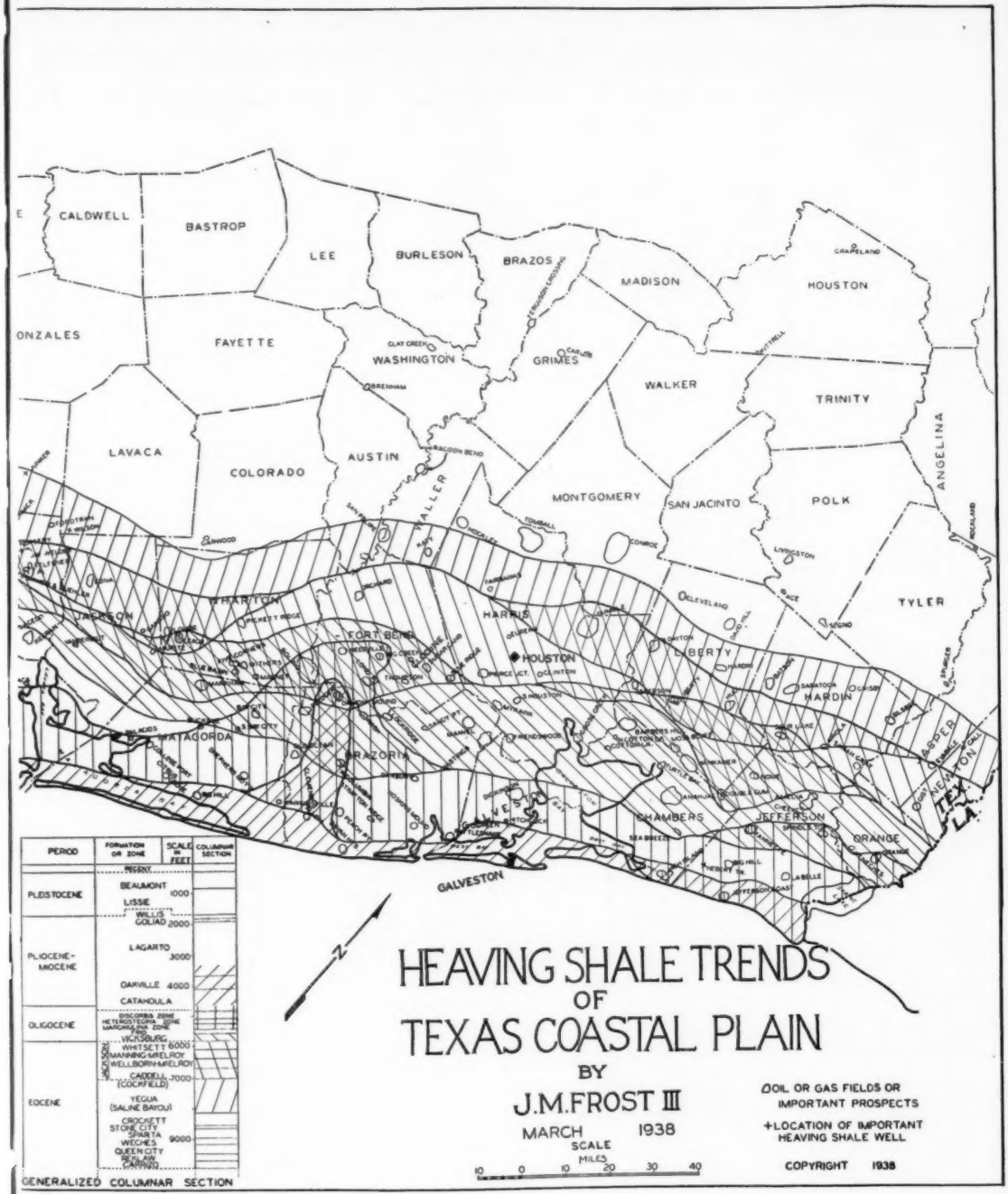
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HEAVING SHALE TRENDS
OF
TEXAS COASTAL PLAIN
BY
J.M.FROST III
MARCH 1938
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OIL OR GAS FIELDS OR IMPORTANT PROSPECTS
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PERIOD
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RECENT
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WILLIS
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PLIOCENE-MIOCENE
LAGARTO
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OAKVILLE
4000
CATAHOULA
OLIGOCENE
VICKSBURG
WHITSETT
6000
MANNING-MELROY
WELLBORN-MELROY
CADDELL (COCKFIELD)
7000
EOCENE
YEGUA (SALINE BAYOU)
CROCKETT
STONE CITY
SPARTA
WECHES
9000
QUEEN CITY
REKLAW
CARRIZO
WILCOX
GENERALIZED COLUMNAR SECTION

FIGURE 1

TABLE I

FIELDS AND WELLS WHERE HEAVING SHALE HAS BEEN ENCOUNTERED IN TEXAS COASTAL PLAIN

LOWER MIOCENE	MIDDLE OLIGOCENE	VICKSBURG	JACKSON	YEGUA
Fields and Prospects	*Fields and Prospects*	*Fields and Prospects*	*Fields and Prospects*	*Fields and Prospects*
Allen	Big Creek	Barbers Hill	Agua Dulce	Alta Verde
Big Hill (Matagorda Co.)	Big Hill (Jefferson Co.)	Big Creek	Ariola	Batson
Bryan Heights	Boling	Blue Basin	Blue Ridge	Cabeza Creek
Damon Mound	Citrus Grove	Blue Ridge	Coletto Creek?	Grisby
Fannette?	Damon Mound	Cheek	Double Gum	Hull
Green Lake	Fannette	Clodine	Edna	La Bahia
High Island	Hawkinsville	Coletto Creek?	Evadale	Leach
Jefferson Coast	High Island	Damon Mound	Gist	Lucas
West Columbia	Hitchcock	Double Gum	Hull	South Liberty
	Jefferson Coast	Fannette	Humble	Sour Lake
	Nash	Goose Creek	Leach	
	North Dayton?	Leach	Markam	*Wildcat Wells*
	Orange	Lockridge	Nome	Felmont, Ernest 1
	Peach Point	Markam	Orchard	Penn-Shell, Junker 1
	Rattlesnake	Moss Bluff	Premont	Howeth-O'Neil, King Est. 1
	Seadrift	Mykawa	Sarah Gray	Quintana, McCormick 1
	Shepherd Mott	Needville	Sarco Creek	Guiberson, Wedemier 1
	Spindletop	Nome	South Liberty	Humble, Wilson 1
	Stratton Ridge	Orange	Telfener	
		Port Neches		
	Wildcat Wells	Sea Breeze	*Wildcat Wells*	
	Magnolia, Hebert Trust 1	Sour Lake	E. M. Jones, Adams 1	
		Spindletop	Magnolia, Freeman 1	
		South Liberty	Texas Gulf Producing, Hearne 1	
		Telfener	Nichols-Bruner, Heldenfels 1	
		West Columbia	Willis Storm, Hobbs 1	
			Plymouth, Jay Welder 1	
			Gulf, Mahon & Buehler 1	
			Bowles, Menger 1	
			Phillips, Morgan 1	
			Gibson and Benedum & Trees, Parks 1	
			Independent, Quincy 1	
			Argo, Soehnge 1	
			Humble, Thompson 1	
			Humble, Wood 1	

data. It may be extended farther south down the regional dip. The limits of the trends overlap and it may be noted in Table I that several fields are listed in more than one column. This is because more than one zone heaved in one locality; therefore, the trends overlap.

The limits of the trends include fields where no heaving shale has been found; nevertheless, these fields are in the trend of a certain formation which has heaved and is likely to heave. In a few places, fields or wells seem to be out of their trend, but the chances for discrepancies are obvious. The best that can be done is to consider each trend in general as far as evidence will substantiate it; hence the abrupt termination of the trends in South Texas.

The map and the table show all the places and formations where heaving shale has been reported, thus indicating in advance of further drilling the probability of encountering heaving shale. This information should be helpful in evaluating prospects and leases.

The writer is indebted to R. H. Cuyler, of The University of Texas, under whose leadership he has worked, and to A. K. Tyson, of the Continental Oil Company, who suggested the subject as a research problem and contributed considerable information. Also, he is grateful to E. S. Post and Charles Leyendecker. Many companies and men in the oil industry gave their whole-hearted coöperation.

Realizing the lack of even a fairly complete bibliography on this subject, the writer has spent considerable time searching all available indexes, and has corresponded with many libraries throughout the United States in compiling the following bibliography on heaving shale.

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VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 220-245, 10 FIGS.

GEOLOGY AND DEVELOPMENT OF KEOKUK POOL, SEMINOLE AND POTTAWATOMIE COUNTIES, OKLAHOMA[1]

H. L. RAU[2] AND K. A. ACKLEY[2]
Seminole, Oklahoma

ABSTRACT

The Keokuk pool, which is located in Seminole and Pottawatomie counties, about 10 miles north of the town of Seminole, Oklahoma, in Ts. 10 N., R. 6 E., is unique in that it was the first pool in Oklahoma to maintain reservoir pressures through voluntary restriction in the rate of production. It is located in one of the few areas where the Misener sand is of sufficient thickness to afford good reservoir conditions.

The structure of the Keokuk pool is anticlinal and is faulted on the east side. This area was probably affected by at least three periods of structural adjustment, but the one which is probably the chief cause of the faulting and folding in the Keokuk pool occurred in early Pennsylvanian or late Mississippian time.

From 106 wells producing from the Misener sandstone and the Hunton limestone the pool has produced 6,362,224 barrels of oil to January, 1938. This is equivalent to 60,021 barrels per well on a basis of 20-acre spacing covering practically all of the productive area. A final recovery of 8,000 barrels of oil per acre is anticipated.

INTRODUCTION

The Keokuk pool is in Ts. 10 and 11 N., R. 6 E., in the northwest part of Seminole County, and the northeast part of Pottawatomie County, Oklahoma. Most of the pool is in Seminole County. Only the extreme north part is north of the Canadian River, which is the boundary of the two counties.

TOPOGRAPHY

Gently rolling plains mark the general topography of this area. It is drained by rather deep intermittent streams which flow into the North Canadian River. The flat gradient of these streams indicates the old age of the topography.

HISTORY

The original surface work for the Carter Oil Company in this area was done by Dolman in 1922. It was checked in 1926 by S. M. Willis who made a complete study of the outcrops. On the basis of favorable indications, several tests, most of which were dry, nearly surrounded the present Keokuk pool. There were three wells, however, which produced and were later known to be edge wells. One of these, the Prairie's Weimer No. 1, in SE. ¼, NE. ¼, NE. ¼ of Sec. 22, T. 10 N., R.

[1] Read by title before the Association at New Orleans, March 18, 1938. Manuscript received, June 22, 1938.

[2] Carter Oil Company. Acknowledgment is made to W. W. Brown, of the Carter Oil Company, for helpful criticism.

6 E., which was drilled in 1927, was a producer and is still making some oil. On the basis of subsurface information obtained from these test wells, together with the surface information which had been worked out, a fairly accurate idea of subsurface conditions, indicating

FIG. 1.—Map showing location of Keokuk pool.

a "high" in the present productive area, was anticipated. This was later proved to be true.

Acreage was purchased in the area that now constitutes the Keokuk pool on the basis of surface indications by the Carter Oil Company and several other operators, before any tests were drilled. Later, as subsurface information was obtained, more leases were bought in favorable spots, and, at a still later date, geophysical information enabled the companies to round out their acreage blocks. It is noteworthy that most of the productive leases were acquired before any wells had been drilled in the immediate area and prior to any knowledge other than that deduced from surface indications.

As a result of the gathering of all of the foregoing information

into a workable whole, a well was drilled in the center of the N. ½, NW. ¼, NE. ¼ of Sec. 2, T. 10 N., R. 6 E., Seminole County. This well is known as the Carter *et al.* Keokuk No. 1 and was completed in February, 1933. The Misener sand, the pay zone, was encountered at 4,090 feet and was penetrated to a depth of 4,106 feet. From this depth the well flowed 1,900 barrels of 41° gravity oil in 24 hours through tubing.

Prior to the drilling of this well all of the companies holding leases in the area organized the community block known as the Keokuk 28 block. The purpose of this organization was to carry on an orderly and efficient development and production program, thereby eliminating all competitive and wasteful drilling.

The completion of the Carter *et al.* Canard No. 1 in the center of the S. ½, SW. ¼, SE. ¼ of Sec. 2, T. 10 N., R. 6 E., as a producing well indicated a pool of commercial importance, and a slow orderly development of the pool followed.

Stratigraphy

Surface.—The surface of this area belongs to the Pontotoc group of sands and shales, which are Upper Pennsylvanian in age. The Geologic Map of Oklahoma[3] shows the surface formation to be undivided Pennsylvanian-Permian, but the presence of the underlying Pawhuska limestone, which is definitely Pennsylvanian, and is encountered at approximately 80 feet below the surface, indicates that the surface rocks are uppermost Pennsylvanian in age. The normal dip of these surface beds is approximately 80 feet per mile toward the west. There is a series of *en échelon* faults extending through this area, whose general strike is about N. 45° W. This faulting is thought to be normal in type.

Subsurface.—The writers have used the nomenclature that has been commonly used during the development of the surrounding pools. As a few of the Pennsylvanian markers have no definite correlation, an attempt to make a definite correlation of them in a paper of this kind would be useless.

Approximately 3,700 feet of Pennsylvanian sediments and 375 feet of Mississippian are encountered before the Silurian and Devonian producing zones are reached. There are many distinct markers encountered even in the Upper Pennsylvanian with which, because of their thickness and extent, close correlations can be made.

Since all wells in the Keokuk pool were drilled by rotary methods,

[3] *Geologic Map of Oklahoma* (1926). Compiled by Hugh D. Miser, United States Geological Survey.

all subsurface data were derived from microscopic study of drill cuttings.

Although definite correlations have been made of the following formations where they crop out, it is very difficult to identify them from subsurface samples. The subsurface units have been given surface names, but the positive correlation of some of them with surface formations has not been established. It is even possible that a few of these Pennsylvanian beds are not represented at this distance from their type locality.

The subsurface formations are shown in the generalized columnar section (Fig. 2) and are discussed in the order in which they are encountered by the drill. Although described many times by other writers, they are here reviewed for the sake of completeness.

PENNSYLVANIAN

VAMOOSA FORMATION

Pawhuska limestone.—The Pawhuska is light gray to white, dense to finely crystalline limestone, lying approximately 80 feet below the surface. It is the first known marker in the Keokuk pool. This bed is of variable thickness, averaging about 10 feet. Morgan,[4] in his description of it in the Stonewall Quadrangle, places it at the base of the Vamoosa formation. Underlying the Pawhuska is a series of undifferentiated sands and shales. This overlies the next mappable unit which is the Belle City.

FRANCIS FORMATION

Belle City.—This bed is gray, brown, finely crystalline to platy dolomite grading into gray, brown, argillaceous dolomite. Belle City is the manuscript name given by Boone Jones to this formation. The name is after Belle City, a village in Seminole County. The Belle City is encountered about 880 feet below the surface. Underlying the Belle City is a series of sands and shales with some intervening limestones and cherty sandstones.

Hogshooter limestone.—The Hogshooter limestone is found at an average depth of 1,470 feet. It is gray to brown, massive limestone, partly dolomitic, and contains many fossils. It has a thickness in this area of 20–30 feet. It is thought to occur in the lower part of the Francis formation.

[4] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2* (Norman, Oklahoma, 1924), pp. 133–37.

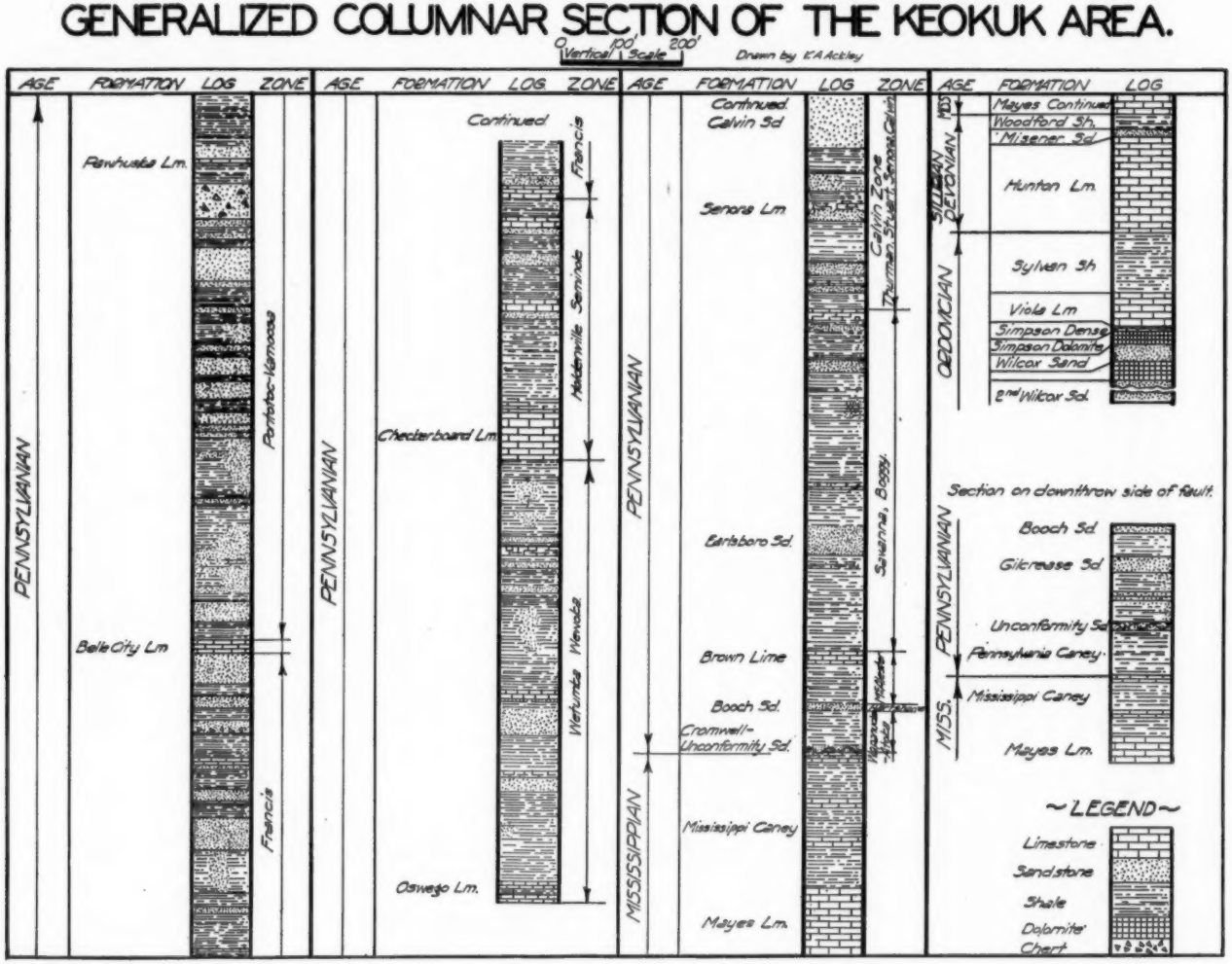

FIG. 2.—Generalized columnar section in Keokuk area.

SEMINOLE-HOLDENVILLE ZONE

The beds between the Hogshooter limestone and the underlying Checkerboard limestone are composed essentially of shale and a few sandstone beds. There are, however, two thin limestones a short distance below the Hogshooter which are tentatively placed in the Seminole formation, and, for the purpose of this paper, are not separated from the underlying Holdenville formation.

Checkerboard limestone.—The Checkerboard is one of the most reliable key beds in the Middle Pennsylvanian section. Its reliability as a marker is because of the unmistakable appearance of the argillaceous green-gray limestone at its top. This argillaceous limestone, 10–30 feet thick, grades into well defined limestone which is gray or brown, and finely crystalline to dense. The basal part, however, is arenaceous and dolomitic. The Checkerboard occurs very close to the base of the Seminole-Holdenville zone.

The true Checkerboard limestone of the outcrop occurs *above* the Seminole formation though the foregoing usage is consistent with general usage of subsurface workers. Probably the subsurface "Checkerboard" is not the same as the surface unit.

WEWOKA-WETUMKA ZONE

The underlying Wewoka-Wetumka zone is represented by a series of sandstones, limestones, and shales which are more or less constant in interval and character. One hundred and thirty feet below the Checkerboard is a mixed zone of sandstone, shale, and some limestone, about 90 feet in thickness. The underlying 150 feet is essentially shale with a few sandstone "shells." Next, a limestone approximately 10 feet in thickness is encountered. It is gray, dense, finely crystalline, and is correlated with the Oolagah or "Big lime" of north-central Oklahoma. Below this is another sand body about 50 feet thick locally containing some stain of petroleum. Next is about 250 feet of shale containing a sand body near the top with showings of oil which might be found to be commercially productive in a few places. The Oswego limestone marks the base of the Wewoka-Wetumka zone.

Oswego limestone.—The Oswego limestone is found at approximately 2,600 feet. It is also an important key bed, maintaining a constant interval up to the Checkerboard and down to the pre-Pennsylvanian. In the Keokuk area its thickness ranges from 10 to 30 feet. It is not a massive limestone, but has intervening beds of gray shale and here and there sandstone "shells." It is characterized by coarse crystalline texture, and by large crinoidal masses imbedded in pheno-crystalline style. The Oswego is thought to be correlative with the Fort Scott limestone of northern Oklohoma and Kansas.

FIG. 2.—Generalized columnar section in Keokuk area.

CALVIN-THURMAN ZONE

Included in the Calvin-Thurman zone are the Calvin, Senora, Stuart, and Thurman formations.

Calvin sandstone.—Immediately under the Oswego limestone, at an average depth of 2,640 feet, is the Calvin sandstone. It is the top member of the Calvin-Thurman zone, and is a massive bed 60–80 feet thick. The Calvin is composed of medium to coarse sand grains which are angular to sub-angular, and afford good porosity. This sandstone contains gas and oil in commercial quantities in parts of the Keokuk pool.

The remaining part of this zone is composed essentially of sandstones and shales, with here and there a thin limestone "shell." As no key horizons have been determined in this part of the section to aid in correlations, no attempt has been made to subdivide the zone. None of the zones below the Calvin sandstone in this particular group has yielded showings of oil or gas.

BOGGY-SAVANNA ZONE

The contact of the Boggy-Savanna zone with the base of the foregoing zone is arbitrarily placed, and as the indefinite nature of the foregoing zone prohibits exact correlation, the statement applies to the top of the Boggy-Savanna zone.

The Boggy-Savanna zone consists of shale with numerous sand zones and is approximately 550 feet thick. The only important zone in this series is the Earlsboro sandstone, a gray, medium fine-grained, mineralized, silty sand. It derives its name from the town of Earlsboro, a short distance from Seminole, where oil was first produced from this zone. This sandstone, which is lenticular in nature, will also undoubtedly be proved productive in parts of the Keokuk pool. The Earlsboro is found approximately 350 feet below the arbitrary top of the Boggy-Savanna.

MCALESTER-HARTSHORNE ZONE

The Brown limestone, near the top of the McAlester-Hartshorne zone, is an excellent marker. The Booch sandstone, near the base of the zone, is thought to be the equivalent of the Hartshorne sandstone. Although the Hartshorne sandstone is represented by a thickness of several hundred feet in its type locality in the McAlester basin, thinning toward the north has reduced these beds to the relative thinness of the Booch.

The Brown limestone is, as its name implies, brown, fine to medium crystalline, and gray, finely crystalline to dense, flaky in struc-

ture and broken by intervening shale beds. It is an excellent marker because of its extensive areal range and fairly constant character.

The Booch sandstone is 85 feet below the top of the Brown limestone and is an easily recognizable bed because of its high mica content. It is composed of medium-size sand grains and is highly mineralized with pyrite and coarse mica flakes. The Booch is very shaly and has low porosity, but it is continuous throughout the Keokuk pool and is a good producer in near-by fields. It has an average thickness of 13 feet at Keokuk, and should produce commercially at certain spots on the Keokuk structure and not at others because of lateral gradation into shaly sand.

ATOKA-WAPANUCKA ZONE

In the producing part of the field the Atoka-Wapanucka zone is represented by approximately 60 feet of shale and 5–20 feet of broken sand which lies unconformably on the Caney member of Mississippian age. This sandstone is here referred to as the "Cromwell unconformity sand"; however, it is possible that this "unconformity sand" is a remnant of the Gilcrease sandstone which in a normal section on the south and east would lie above the Wapanucka limestone. It is a medium to coarse angular and sub-round sand, in places cherty, generally non-porous, although where it was found to be porous favorable showings of oil and gas were noted and it is anticipated that a few wells will produce commercially from this zone.

Off structure, east of the pool, a slightly different section was encountered which embraces more of the members of this group, including the Gilcrease sandstone, the Wapanucka limestone, and the true Cromwell sandstone.

The Gilcrease sandstone, which is in the Atoka formation, is medium-grained, somewhat calcareous, and in places contains nodular glauconite. It is about 50 feet below the top of the Booch and has a thickness ranging from 5 to 15 feet.

The Wapanucka limestone, where encountered, has a thickness of a few feet and grades directly into sandstone. The writers feel that a detailed discussion of this zone is unnecessary since it was encountered in only one well. It will be discussed later.

The Pennsylvanian Caney is encountered in a few wells off structure but is not believed to be present on structure.

MISSISSIPPIAN

Caney shale.—The Caney shale, the youngest formation of Mississippian age, has an average thickness of 200 feet. It is composed essen-

tially of black and gray shales, which have a characteristic chunky fracture. These shales are interbedded with gray-brown medium-crystalline dolomitic limestones in the upper part. At the base the formation becomes gray-brown calcareous gritty shale which grades downward into limestone.

Mayes limestone.—The Mayes limestone lies beneath the Caney shale and at places the top is difficult to determine because of the close resemblance between it and the calcareous shale of the Mississippian Caney above it. In appearance the Mayes is gray to brown in color and finely crystalline to sugary or gritty in texture. The basal 5–10 feet is characterized by disseminated nodular glauconite. In a few places a thin bed of gray finely crystalline limestone, termed the Welden, has been encountered at the base of the Mayes.

MISSISSIPPIAN-DEVONIAN

Woodford shale.—Conformably underlying the Mayes and Welden formations is the Woodford shale. The term Woodford is general field usage for the widely known Chattanooga shale. It has an average thickness in the Keokuk area of 23 feet. The Woodford is brownish black shale having a golden tinge and a brown streak. It is locally very pyritic and in places cherty. The Woodford has been generally considered as Mississippian in age, but recent paleontological correlations by some authors have identified some of the conodonts found in the Woodford as Devonian in age.

Misener sandstone.—The Misener sandstone is the main producing formation in the Keokuk pool. It is a medium-fine to medium-grained, rounded to sub-rounded, well sorted, tightly cemented sandstone having an average porosity of 10 per cent and an average permeability of 75.9 per cent. Its thickness ranges from 3 to 33 feet, the average being 14½ feet for the entire field.

In the south part of the field the Misener is generally an uninterrupted sand body which lies directly on Hunton limestone.

In the central part of the pool the Misener is, in places, interrupted by chert beds and in places is partly dolomitic. In one well which had a thick section of sandstone the Misener was found to have a definite chert zone below which was a continuation of typical Misener sandstone. Ordinarily the base of the Misener in the central part is characterized by a chert bed which directly overlies the Hunton limestone.

In the northern part, particularly on the north side of the Canadian River, the condition changes abruptly, and the Misener horizon is represented by dolomitic sandstone, hard cherty dolomites, and "shells" of chert which have not been found to be good reservoir

rocks. The position and location of this mixed zone is shown in Figure 3. It may be noticed that this zone has the form of a wedge whose apex lies between Sec. 11 and Sec. 2, T. 10 N., R. 6 E. This zone continues to thicken to the extreme northern part of the field where only a few feet of good Misener sandstone is present.

This zone is in places very fossiliferous and brachiopods from the cores were identified as *Spirifer duodenaria* and *Spirifer tribulus*.[5] These fossils are thought to have a rather limited range in the Helderbergian and Oriskanian of Lower Devonian age which also embraces

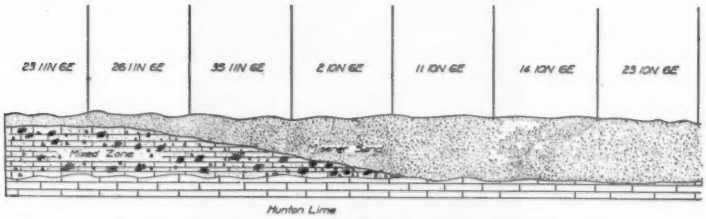

FIG. 3.—Sketch showing position of "Mixed zone" between Misener sandstone and Hunton limestone.

the Haragan member of the Hunton limestone. This correlation is further substantiated by the presence of an ostracod identified as *Pachydomella longular*.[6] This fossil has a range limited to the Haragan. Since this mixed zone is apparently Hunton in age it is probable that it is not an integral part of the Misener although the similar characteristics of the sand found in the two bodies suggest a similar source.

The mode of deposition of the Misener sand has long been a bone of contention among Mid-Continent geologists. The writers do not attempt to give conclusive evidence for its solution, but in discussing the character of the chief producing zone this problem must necessarily be considered. It is hoped that evidence given in this paper may be helpful.

Lon B. Turk[7] points out in his support of the windblown theory of the origin of the Misener sand that the sand ordinarily attains its greatest thickness on the leeward side of old Hunton hills and in the deep protected troughs and synclines of these hills. He has excellent supporting evidence of this theory in other Misener pools. In Sections 14 and 11, T. 10 N., R. 6 E., the Misener has a thickness of 22–24 feet on the top of a very pronounced Hunton "high." As this repre-

[5] Personal communication with C. E. Decker.

[6] Personal communication with R. W. Harris

[7] Personal communication with Lon B. Turk.

sents almost the maximum thickness of the Misener section, it does not lend confirmation to the windblown theory.

In the Shell Petroleum Corporation's Boley No. 1, recently drilled in the SE. ¼, SE. ¼, SW. ¼ of Sec. 8, T. 11 N., R. 6 E., a core from the Misener sandstone contained several brachiopods and a few conodont skeletal fragments.[8] This well is approximately 3½ miles northwest of

FIG. 4.—Photomicrograph showing brachiopod and a few conodont skeletal fragments. Magnification, approximately ×3. Part of core from Misener sandstone in Shell Petroleum Corporation's Boley No. 1, SE. ¼, SE. ¼, SW. ¼, Sec. 8, T. 11 N., R. 6 E.

the north end of the Keokuk pool. A photomicrograph of a piece of this core is shown in Figure 4.

The presence of dolomite and chert in the aforementioned "mixed zone" can be explained by secondary mineralization of the Hunton limestone, but the only apparent reason for the existence of the sand in this body is marine sedimentation. Since the sand in the Misener is very similar to the sand in the mixed zone, perhaps the Misener is also marine in origin and is a gradational feature of the mixed zone.

SILURO-DEVONIAN

Hunton limestone.—The Hunton limestone has an average thickness of 142 feet in this pool. No attempt has been made definitely to

[8] Identified and photographed by R. W. Harris.

subdivide the Hunton formation but it is thought that the Bois d'Arc, Haragan, Henryhouse, and Chimneyhill are represented here. Paleontological evidence already presented indicates the presence of the Haragan and a core taken from the Carter Oil Company's Canard No. 1, center, S. ½, SW. ¼, SE. ¼ of Sec. 35, T. 11 N., R. 6 E., showed green shale "breaks" at approximately 45 feet below the top of the Hunton which would probably be part of the Haragan-Henryhouse formation.

The Hunton limestone in this area is medium-coarse crystalline limestone, gray in color, but in places brown from oil staining, and having here and there inclusions of pink, medium-coarse crystalline phenocrysts. Also, some dolomitic limestones are generally encountered. Oil staining is evident throughout most of the Hunton section where it is found on structure and has been penetrated by the drill. There are three pay zones in the Hunton limestone. The first is found at the top of the formation underlying the Misener sand. The second pay zone is separated from the first by approximately 20 feet of hard, tight, barren limestone. Near the basal part of the Hunton is another zone which is found to be productive in a few wells. Though the Misener is the chief producing zone of this pool, the Hunton has in many places yielded good production and will no doubt add much to the ultimate recovery.

ORDOVICIAN

Sylvan shale.—Below the Hunton lies the Sylvan shale, a grayish green splintery shale containing disseminated pyrite. The average thickness of the Sylvan is 96 feet in this area.

Viola limestone.—The Viola has an average thickness of 40 feet and is composed of coarsely crystalline gray and white mottled limestone. Some staining has been noted in the Viola but it is not believed that it will be found commercially productive.

Simpson formation.—This formation lies directly below the Viola and the top is marked by a thin bed of brown dense limestone ranging from 2 to 5 feet in thickness. This formation is commonly termed the Simpson "Dense." Underlying the "Dense" is gray-brown fine to medium crystalline dolomite varying in thickness from 20 to 30 feet and becoming sandy at the base. The common field term for this member is the Simpson "Dolomite." This member generally contains stains where encountered on structure.

"First Wilcox" or *"Seminole" sandstone.*— The overlying Simpson dolomite, which is sandy at its base, grades into a well defined sand body which is known as the "First Wilcox sand" or "Seminole sand." This is the major producing zone in the Seminole area. This sand is

composed of subangular, subrounded, and some well rounded grains. The sand in the "Dolomite" and at the very top of the formation is well rounded. The sandstone produces in the extreme north end of the Keokuk pool and it is believed that it will produce commercially in the highest parts of the central and south parts also. The Seminole sandstone attains a thickness of 30 feet in the Carter Oil Company's Canard No. 1.

A "break" consisting of fine to medium crystalline dolomite separates the "First Wilcox" or the "Seminole sand" from the "Second Wilcox sand." In the Canard No. 1 the thickness of this "break" is 43 feet. This body of dolomite also changes into the "Second Wilcox sand" very gradually. The "Second Wilcox" is characterized by coarse, rounded, frosted grains at the top and medium-well rounded grains lower in the formation. This sand is probably 700–800 feet thick and has a few thick shale "breaks." It has been penetrated only 17 feet in the Keokuk area. In the three wells that were drilled to the "Second Wilcox sand" no staining was encountered in either the dolomitic break or the sand. Both of these zones are productive in near-by areas.

Structural History

The structural history of the Keokuk pool was affected by at least three periods of adjustment with intervening periods of submergence and more or less continuous deposition: (1) the post-Arbuckle–pre-Simpson, (2) the post-Hunton–pre-Chattanooga, and (3) the early Pennsylvanian.

Although none of the wells in this area has penetrated beyond the "Second Wilcox" in the Simpson, it is reasonable to assume that this area was affected by post-Arbuckle–pre-Simpson adjustment as is north-central Oklahoma. During Arbuckle time, which extended from Upper Cambrian to Lower Ordivician, there was a slight warping and partial emergence. At the end of Arbuckle time there was a shallow but rather general submergence which permitted the deposition of the sediments from Ordovician to late Devonian.

Following the Hunton and preceding Woodford or Chattanooga deposition there was a general emergence of the landmass in northeastern and north-central Oklahoma with subsequent erosion. This period of erosion truncated the beds of the pre-Hunton to the Arbuckle in the northern part of the state. The Keokuk area, although probably elevated during this time, did not undergo a great amount of erosion, since there are in places 160 feet of Hunton present. During this period of erosion, the Hunton limestone, being for the most part

highly soluble, became leached and porous at its unconformity surface. This made possible the present oil reservoir from which a small part of the Keokuk production is obtained.

After this post-Hunton emergence, subsequent encroachment of the water led to the deposition of the Woodford shale, and possibly the

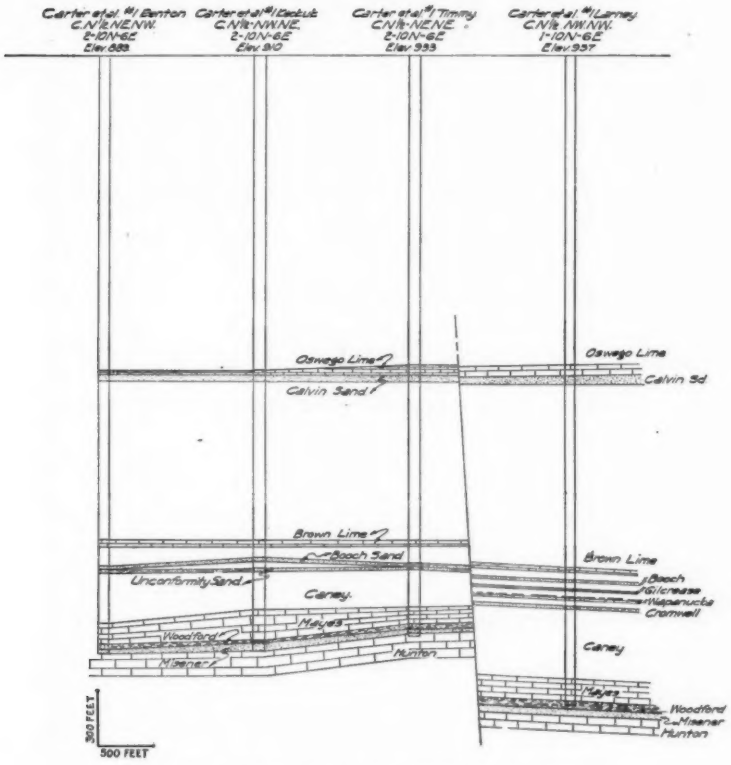

FIG. 5.—West-east section *AA'* (Figs. 6 and 7).

Misener sandstone which underlies the Woodford. The Chattanooga sea must have been comparatively deep and quiet as evidenced by the even and widespread distribution of the Chattanooga shale. The presence of well preserved fossils such as conodonts and plant spores, which were very fragile and delicate before their deposition, seems to indicate a non-turbulent sea. This supposition is borne out further by the subsequent deposition of the limestones and shales of the Upper

FIG. 6.—Map showing subsurface structure contoured on Misener sandstone.

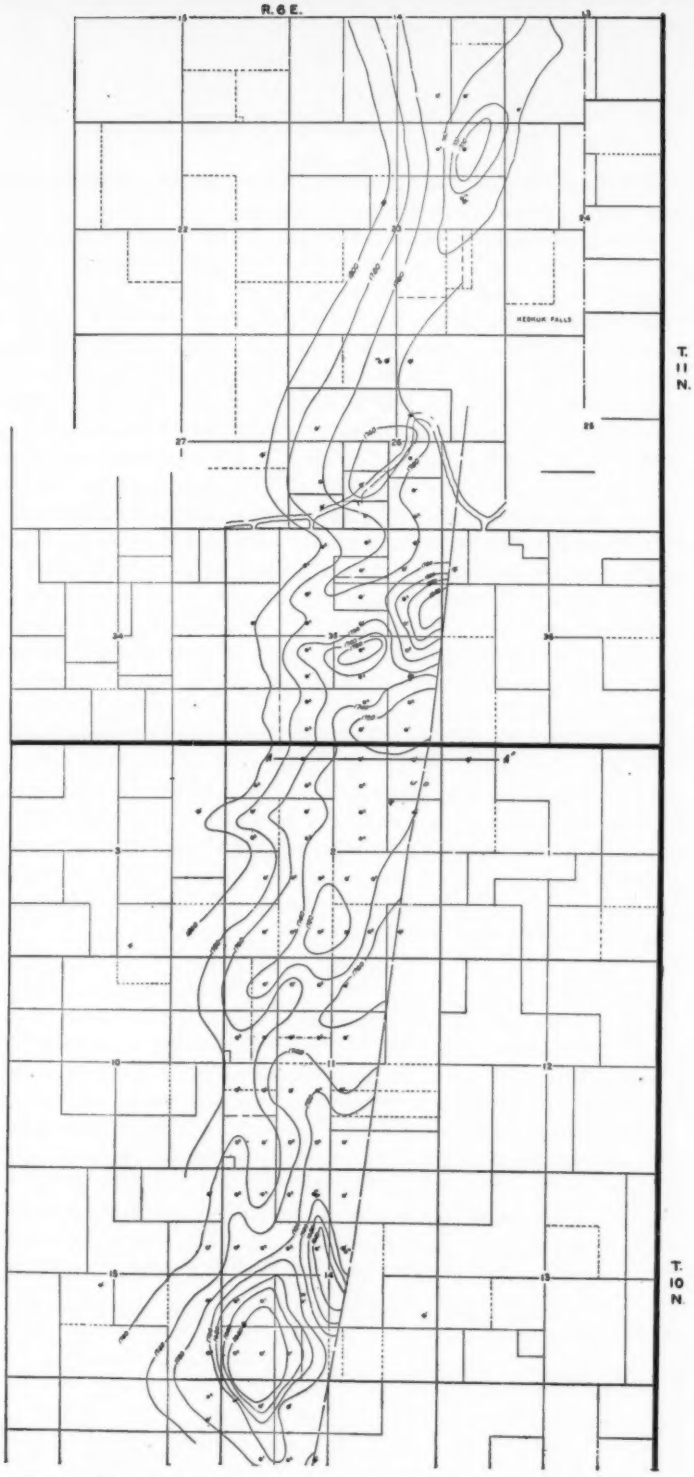

FIG. 7.—Map showing subsurface structure contoured on Calvin sandstone.

Mississippian, which include the Sycamore, Mayes, and Caney, apparently conformably on the Chattanooga.

The structural adjustment, which is probably the principal cause of the faulting and folding in the Keokuk pool, occurred in early Pennsylvanian time. The faulted condition shown in Figure 5 must have occurred during this time. There is a much thicker section of Caney on the downthrown side of the fault, part of which is Pennsylvanian Caney. The section on the downthrown side also shows the presence of the Gilcrease sandstone, a fingering of Wapanucka limestone, and some true Cromwell sandstone, all of early Pennsylvanian age, and all of which are not present on the upthrown side of the fault. This suggests that the faulting probably occurred at the end of Gilcrease time and that the upthrown side was subjected to erosion which removed the sediments from the Gilcrease down to the Mississippian Caney. Faulting must have continued along this plane since there is some evidence of vertical displacement throughout the Pennsylvanian section.

It has been pointed out by A. I. Levorsen[9] that during Pottsville time (Lower Pennsylvanian) there was faulting in a great many places and that nearly all of these faults were of the normal type, generally trending N. 5° 25′ E. The faults shown in Figures 6 and 7 have a general strike of N. 7°–10° E., but they were probably a result of the same movement that faulted the rocks in eastern Oklahoma during Pottsville time. It is thought by the writers that the system of *en échelon* faulting which is evident on the surface is a direct result of horizontal differential movement along the underlying pre-Mississippian fault zones, although the probable age of the surface faulting is post-Pennsylvanian or Permian.

FOLDING

Figures 6 and 7 are maps contoured on the Misener sandstone and the Calvin sandstone, respectively. It is obvious that in a general way the structural features of the Misener are reflected up into the Pennsylvanian. It is quite possible that the Calvin structure is due to a depositional feature, because of the probably rough topography of the Hunton unconformity. However, if the closing structure on the Calvin is a result of deposition over Hunton hills, the axes of these structures would coincide in more or less the same vertical plane. Since there is a definite axial shift toward the south and west, it is the writers' opinion that the structure is of diastrophic origin rather than

[9] A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (March, 1928).

depositional. This folding probably took place in post-Pennsylvanian or Permian time. The magnitude of the structure decreases toward the surface as is the characteristic of most folds resulting from deep-seated horizontal stresses.

FAULTING

The fault in the Carter Oil Company *et al.* Grisso No. 1, center, N. ½, SE. ¼, NE. ¼ of Sec. 2, T. 10 N., R 6 E., is one of the most interesting structural features of the pool. Although there is good evidence of a fault where shown in other figures, the only well actually in contact with the fault is the Grisso No. 1, as shown in Figure 8. This well maintained a normal section to the Woodford shale and after going through an exceptionally long Woodford section a repetition of the Caney shale was encountered, thus cutting out the Misener and Hunton. After drilling in Caney for 68 feet the Sylvan was found and the section continued to be normal as deep as the hole was drilled. The operators, realizing that the well had cut a fault, attempted to recross the fault and divert the hole into the productive Misener on the upthrown side. An Eastman directional survey was taken and an Eastman whipstock was set to drill due west with a drift of 13°. The directional survey showed vertical direction to be off 1° in the direction N. 30° E. Preliminary to the directional drilling the hole was cemented back to 2,700 feet with 1,250 sacks of cement. The hole was then drilled out to 2,780 feet and a survey showed the hole to be off 1° bearing in the same direction. Several attempts to divert the hole failed. A survey after each run showed that the new hole was following the path of the original hole. A variation of as much as 4° was noted near the base of the original hole with only 1½° variation at 3,500 feet. This variation allowed the hole to drift as much as 100 feet off vertical, thus lending support to the explanation indicated in Figure 8.

Communitization Plan

The Keokuk Community 28 block, consisting of 1,360 acres in Secs. 1 and 2, T. 10 N., R. 6 E., and Secs. 35 and 36, T. 11 N., R. 6 E., was the first pool in Oklahoma where reservoir pressures were maintained through voluntary restriction in the rate of production. The rate of production was decided by a study of bottom-hole pressures and reservoir conditions. This bottom-hole pressure is being maintained by keeping the rate of production as nearly as possible in balance with the rate of encroachment of edge water.

The Keokuk Community 28 block is operated by the Carter Oil Company which owns approximately 77 per cent. The remaining 23

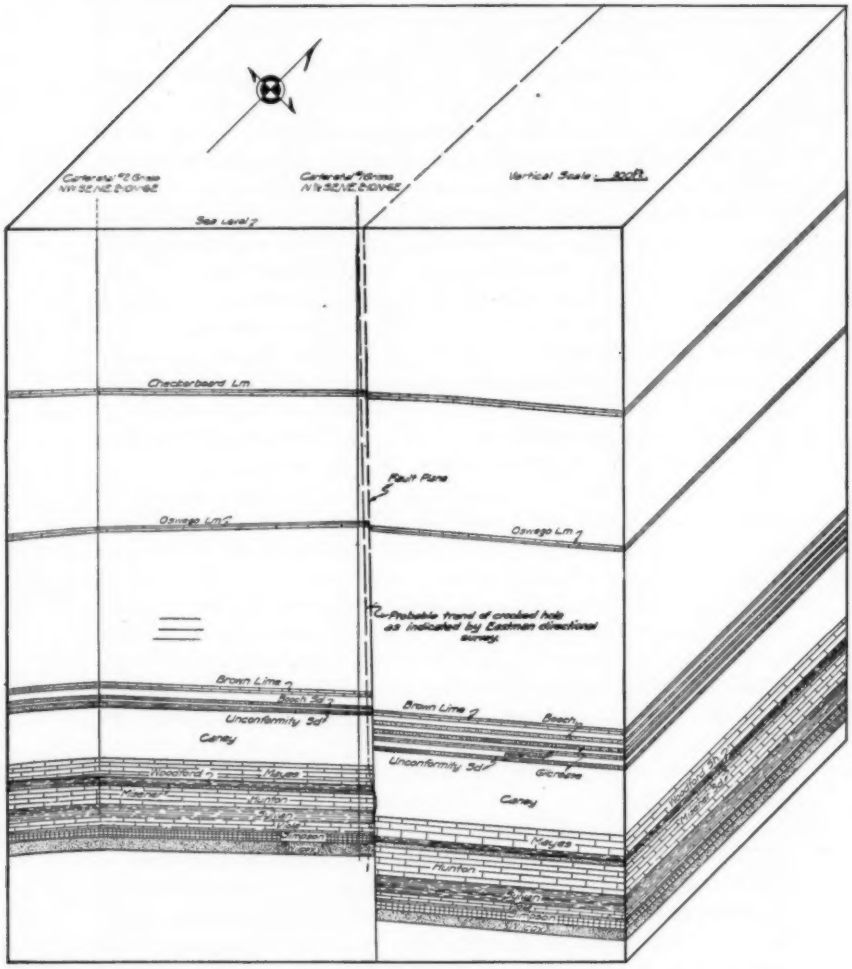

FIG. 8.—Block diagram showing faulted condition in Carter Oil Company's Grisso well No. 1.

per cent is divided as follows: British American Oil Producing Company, 3 per cent; Sinclair Prairie Oil Company, 3 per cent; and Gulf Oil Corporation, 17 per cent.

It was found, when taking an open-flow test on wells in the center of a 20-acre tract, that the bottom-hole pressure on a shut-in offset well was reduced by as much as 30 pounds, indicating that the permeability of the sand was such that with proper control of the rate of withdrawal, this spacing was sufficiently close adequately to drain the reservoir.

At a later date an attempt to inaugurate 40-acre spacing was made. One well, the Carter Oil Company's Black No. 1, in the center of the NE. ¼, SW. ¼ of Sec. 14, T. 10 N., R. 6 E., was drilled under this plan. An agreement to this plan was not reached by all the operators; consequently, the remainder of the wells in the pool were drilled, one to 20 acres.

The original plan of maintaining 20-acre spacing was accomplished by the wells being offset 1,320 feet east and west. However, after the shape of the structure was determined to be narrow east and west, the spacing was changed to 1,320 feet north and south instead.

The value of communitization is illustrated in the orderly manner in which the drilling program was carried out and is marked by the very few dry holes which were drilled to outline the productive limits of the field.

Communitization has enabled production to be limited, regulated, and controlled so that the highest per-acre recovery may be recovered at the least cost. The benefits derived from this type of operation were recognized by other operators outside of the community plan, who realized the economic value of this mode of operation and who consequently adopted the plan essentially along the same lines.

Development

The Carter Oil Company *et al.* Keokuk No. 1, in the center of the N. ½, NW. ¼, NE. ¼ of Sec. 2, T. 10 N., R. 6 E., was drilled to the Misener sandstone with rotary tools. A thorough coring program through all possible pay horizons was followed. The Misener sandstone was encountered at a depth of 4,090 feet, cored to the total depth of 4,106 feet, and a Halliburton test made which showed approximately 500 feet of oil. Eight-inch casing was set at 4,088 feet, 2 feet above the Misener and after drilling plugs the well was bailed in as a flowing well capable of making approximately 2,200 barrels of oil per day, February, 1933.

The next step in the development of the field was the drilling of the Carter Community Canard No. 1 in the center of the SW. ¼, SE. ¼, of Sec. 35, T. 11 N., R 6 E., a north offset to the Carter *et al.* Keokuk No. 1. This well had the Misener sandstone at a depth of 4,065 feet which is 5 feet higher structurally than the sandstone top in the Keokuk No. 1 and 8-inch casing was cemented at this depth. The Misener sandstone was cored continuously to 4,090 feet. The sandstone in this well was 25 feet thick and apparently would have been highly productive but because the other operators wanted to test the "Wilcox" formation, the well was drilled deeper. Subsequently, the Hunton limestone was cored and showed saturation, with possibly the exception of the basal 10 or 15 feet. The top of the Sylvan was found at 4,223, the Viola at 4,315, the dense Simpson at 4,372, and the dolomitic Simpson at 4,375 feet. There were a few slight showings in the dolomite. The "Wilcox" sandstone was topped at 4,398 feet and was cored from 4,398 to 4,403 feet, the recovery containing favorable showings of oil and gas. The 6-inch casing was cemented in the Viola. Standard tools were then rigged up and the hole bailed. After bailing, 1,500 feet of fluid (400 feet of salt water and 1,100 feet of black oil of 27° gravity) rose in the hole. The hole was then deepened with standard tools to the "Second Wilcox sand" which was found at 4,470–4,483 feet, the total depth of the hole. After deepening there was an increase in water which raised the fluid level to 3,000 feet but with no apparent increase in oil.

As the oil from the "Wilcox" was not believed to be in commercial quantity the well was plugged back to the Misener-Hunton zone. The top of the plug was near the basal part of the Hunton. A test at this depth showed 1,500 barrels of oil and 500 barrels of water. In repeated attempts to shut off this water the hole was finally cemented back into the 8-inch casing which was set at the top of the Misener sandstone. The well was completed in the top 5 feet of the Misener sandstone, producing potentially 480 barrels of oil with some water. It is probable that the water was the result of a faulty cement job inasmuch as the south offset, the Keokuk No. 1, did not produce water for a long period although it is structurally lower than the Canard No. 1.

After the completion of these two wells, the existence of a commercial oil pool was assured and a slow and orderly development followed.

Due to the success of the Community surrounding the Keokuk No. 1, another Community plan was formed covering parts of Secs. 23 and 26, T. 11 N., R 6 E.

The discovery well in this block, the Carter Oil Company's Community Ray No. 1, in the center of the W. ½, NE. ¼, NE. ¼ of Sec. 23, found small showings in the Calvin and Misener sandstones, was deepened, and found oil in the "Wilcox" sandstone at 4,531–4,538 feet, producing initially, by swabbing, about 1,200 barrels of oil with some water. This was surprising since the Ray well is 53 feet lower on the "Wilcox" than the Canard No. 1, which did not make a producer in the "Wilcox." Later this well blew out and made an estimated 30 million cubic feet of gas accompanied by salt water from behind the 8-inch pipe which was set in the Viola. Repeated testing by ripping the 8-inch pipe failed to locate the origin of the gas. It is generally assumed to be coming from the Calvin sandstone. It was necessary to run a string of 5-inch pipe to the top of the "Wilcox" to shut off this gas. Only two other "Wilcox" wells were drilled in this part of the field—a north offset and a south offset to the Ray well. All of these wells are now plugged back to the Misener-Hunton zone where they are producing. The accumulated production from the "Wilcox" amounted to 236,216 barrels of oil. The gravity of this "Wilcox" oil is 35.4°.

In March, 1935, the Carter Oil Company completed its Black No. 1 in the center of the NE. ¼, SW. ¼ of Sec. 14, T. 10 N., R. 6 E., in the Misener sandstone at 4,127–4,140 feet, producing an initial flow of 1,090 barrels of oil in 24 hours. As previously mentioned, this well is located in the center of a 40-acre tract, but later wells followed the north-south 20-acre spacing alignment.

In April, 1936, Tom Phillips' Bynam No. 1, in the S. ½, SW. ¼, NW. ¼ of Sec. 26, T. 11 N., R. 6 E., opened the north end of the pool to Misener-Hunton production with an initial flow of about 300 barrels of oil, and about 8 per cent water.

Both in the South Keokuk pool, opened by the Carter Oil Company's Black No. 1 and the North Keokuk pool, opened by the Phillips' Bynam No. 1, the development was much more rapid than that in the Central Community block.

Proration

When the Carter Community Keokuk No. 1 was brought in, it was allowed an initial production of 15,000 barrels of oil as a discovery well. At that time, the state was under proration. The well produced from its inception in March, 1933, until November, 1933, under an average proration of about 30 per cent. At this time the Carter Oil Company and its associates decided that a restricted production program would be of decided ultimate benefit. They asked from the State

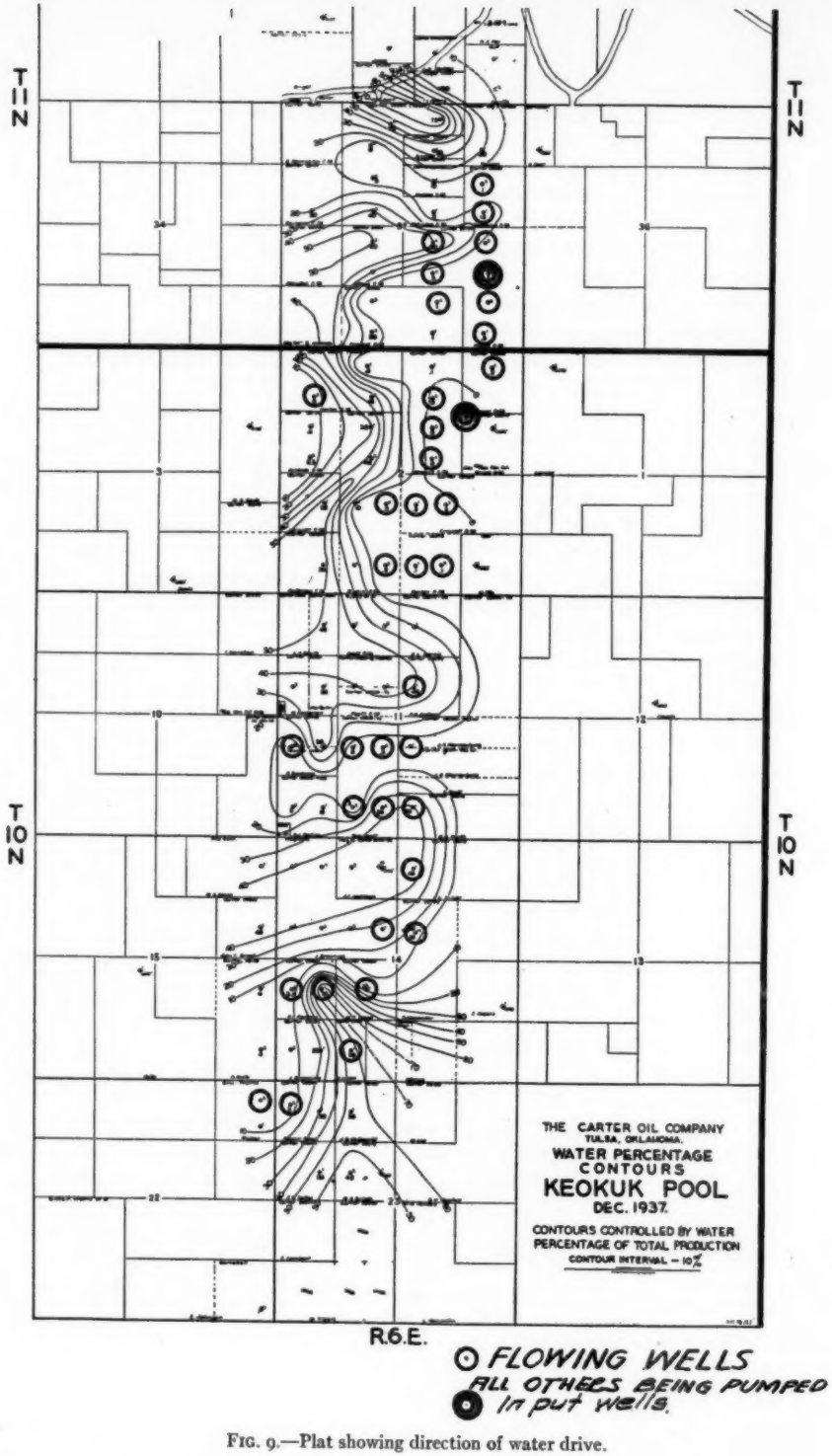

FIG. 9.—Plat showing direction of water drive.

Proration Department and received a reduction amounting to 12 per cent of the potential rating. This percentage was quickly reduced to about 8 per cent following more definite technical findings.

Following the completion of the Carter Oil Company's Black No. 1 in the South Keokuk pool, all the wells in that division, after the Black No. 1 had received 15,000 barrels for discovery rights, were allowed 100 barrels per day flat allowable until April, 1936. At that time new potentials were taken in the entire pool and all production placed on the same percentage allowable which at that time was 8.1 per cent.

In April, 1936, following the opening of the North Keokuk area to Misener-Hunton production and after its initial wildcat allowable of 15,000 barrels of oil, the area was allowed to produce 100 barrels per day. This well and all other wells drilled north of the Central Community block made water very quickly and as a consequence were never entirely prorated.

For the pool as a whole, the potential was reduced at the rate of 3 per cent per month with the provision that at any time the operator could ask for a new potential because of reconditioning, deepening, acidization, or any other operation which had increased the capacity of the well.

Repressuring

The original conception concerning Keokuk production was that of a water-drive type. Following that idea, it was decided that the best recovery would be accomplished by a gas-pressure drive from the top against a water drive from the lower part of the structure. To develop this belief a repressuring program was inaugurated in the central Keokuk pool. The Grisso No. 2 in the NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 2, T. 10 N., R. 6 E., just west of the fault, was drilled primarily to be used as an input well in conjunction with the Riddle No. 2, in the center of the N. $\frac{1}{2}$, SE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 35, T. 11 N., R. 6 E. These wells were used, and are still being used, for gas repressuring purposes. This repressuring program was applied to the original Community Keokuk block only. It has not been in effect long enough to draw positive conclusions but it is anticipated that substantial benefits will be derived from this type of operation. Figure 9 shows the water conditions and bears out the original idea of water drive. It also shows that repressuring has been of definite benefit in the central Keokuk area. The extent of the benefit has not been appraised. At a later date an excellent comparison may be drawn with the south part of the pool since only the central part, or Community block, has been subjected to repressuring.

Production

At the time of completion, practically all of the wells in the Keokuk pool, producing from the Misener-Hunton zone, were flowing wells. By December, 1937, this condition had changed and only 35 wells, of a total of 106 wells, were flowing. Many of those wells which are classed as pumping need only to be agitated to start them flowing. Pumping equipment will be installed in more wells in the near future

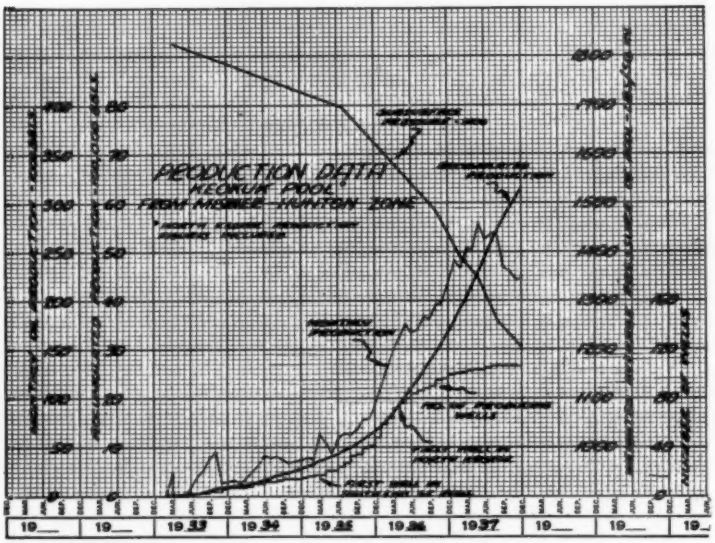

Fig. 10.—Curve showing production from Misener-Hunton zone.

since gas (used in repressuring) can be conserved by agitation of the wells (by pumping) to start them flowing.

The Carter *et al.* Keokuk No. 1, in the center of the N. ½, NW. ¼, NE. ¼ of Sec. 2, T. 10 N., R. 6 E., continued as a flowing well from March, 1933, to December, 1937. At that time it had produced 356,000 barrels of oil. Since December, 1937, the production is primarily flowing since it has only to be agitated by the pump to cause flowing.

The original bottom-hole pressure registered at the discovery well, the Keokuk No. 1, in Sec. 2, T. 10 N., R. 6 E., and the bottom-hole pressure in the Carter *et al.* Black No. 1, in Sec. 14, T. 10 N., R. 6 E., which was not drilled until 2 years later, were practically the same.

To January 1, 1937, from 45 wells in the Community C-28 area, the wells produced an average of 66,965 barrels of oil per well, or 3,348 barrels per acre on a 20-acre spacing plan. In the South Keokuk pool, from 46 wells, the production averaged 66,493 barrels of oil per well and the recovery was 3,325 barrels per acre. In the north part of the Keokuk pool, from 15 wells, an average of 12,687 barrels of oil per well, or 634 barrels per acre was recovered.

An accurate production-decline curve can not be drawn because of the restricted production, reconditioning of wells, *et cetera*, conditions which have been features of the development of the Keokuk pool. However, it is estimated that a recovery of 8,000 barrels per acre may be expected from the Misener-Hunton zone in the central and south parts of the pool. In addition, it is expected that 1,000–2,000 barrels per acre may be recovered from the Pennsylvanian zones. Further, the "Wilcox" may be expected to add materially to the total production of the central and south Keokuk areas.

Conclusions

The plan of wide spacing was inaugurated in the Community to allow economic development. Outside of the Community other operators voluntarily agreed to follow the plan. Because of this orderly development very few dry holes were necessary to define the productive limits of the field. It is not definitely known whether 20-acre spacing is the best plan but from the information presented it is definitely known that this mode of operation is profitable, whereas it is doubtful if closer spacing would have been found so.

As development of this type has been recognized as economically proper, it has been adopted in later developments in Oklahoma and elsewhere.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 246-253, 2 FIGS.

GEOLOGICAL NOTES

EXPOSURES OF VICKSBURG OLIGOCENE FAUNA IN WESTERN LOUISIANA[1]

JUSTIN M. RUKAS[2] AND D. DAVID GOOCH[2]
University, Louisiana

The purpose of this note is to call attention to two Vicksburg fossil localities west of the Red River in southeastern Natchitoches Parish, Louisiana, near the towns of Montrose and Derry (Fig. 1). Heretofore no fossiliferous Vicksburg has been reported west of the Red River.

SECTION AT MONTROSE ON AN OLD ABANDONED ROAD

Sample Ru-543, in the NE. ¼, SE. ¼, Sec. 5, T. 6 N., R. 6 W.

	Thickness in Feet	
Top	25	Medium-grained red sands with small laminae of clay interbedded with a series of locally indurated gray massive sands
	16	Gypsum-bearing yellowish brown sandy clays with irregular lenses of highly fossiliferous calcareous clays
	0.5	Lignitiferous sands
	14	Laminated grayish brown oxidized sandy clays with thin interbedded sand streaks
	12	Medium- to course-grained massive sands
	15	Grayish brown laminated sandy clays

DETAILED BORE-HOLE SECTION AT MONTROSE

Sample Ru-538, in the SE. ¼, NW. ¼, Sec. 5, T. 6 N., R. 6 W.

	Depth in Feet	
Top	2	Medium- to coarse-grained sands
	6	Dark gray heavy sandy clays
	11	Yellowish brown highly fossiliferous clays with abundant shell fragments. (Samples Ru-538-A-B-C-D)
	15	Bluish gray fossiliferous sandy clays with diminishing amounts of shell fragments. (Ru-538-E-F-G-H-I)

DETAILED BORE-HOLE SECTION AT MONTROSE

Sample Ru-544, in the SW. ¼, NE. ¼, Sec. 5, T. 6 N., R. 6 W.

	Depth in Feet	
Top	5	Mottled red and gray sandy clays
	8	Oyster-bearing brown sandy fossiliferous clays with an abundance of shell fragments having a sawdust-like appearance (very compact). (Samples Ru-544-A-B-C)

[1] Manuscript received, December 20, 1938.

[2] Louisiana Geological Survey.

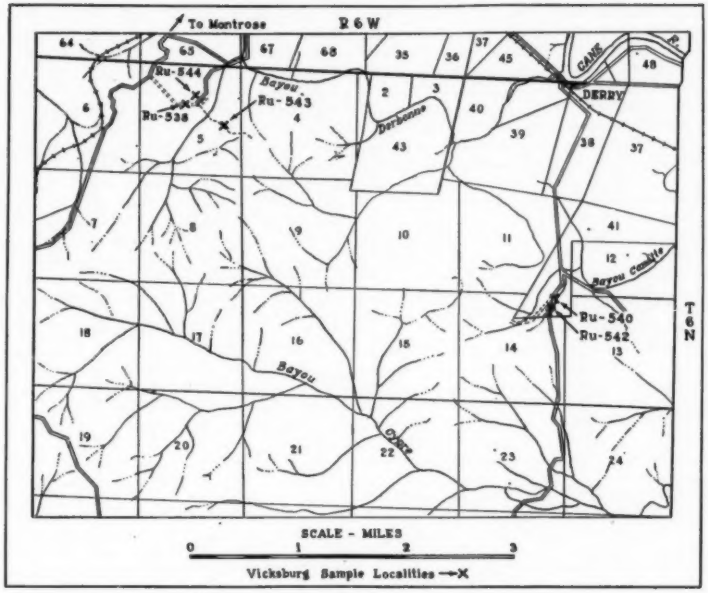

FIG. 1

SECTION AT DERRY (ROAD CUT)

Samples Ru-540, Ru-542, in the extreme south center of irregular Sec. 41 or the NE. ¼, NE. ¼ of regular Sec. 14, T. 6 N., R. 6 W.

	Thickness in Feet	
Top	2	Medium-grained gray sandstone
	30	Dark brown to light brown laminated sandy clays with irregular lenses of sand
	4	Yellowish brown gypsiferous clays associated with a 4-inch ledge of coquina and lenses of highly calcareous shell fragments. (Ru-540-B-C-D, Ru-542, and collections of M. N. Broughton and B. W. Blanpied)
	2	Yellowish light brown gypsiferous sandy clays interbedded with a thin seam of bentonite
	2	Highly gypsiferous gray sandy clays
	5	Yellowish brown medium-grained sands
	3	Gray slightly oxidized laminated sandy gypsiferous clays

Several members of the Shreveport Geological Society, mainly, R. T. Hazzard, B. W. Blanpied, and M. N. Broughton, visited these localities and made collections of macro-fossils which they later submitted to T. Wayland Vaughan and J. D. Sears of the United States Geological Survey for determination. Samples were also collected by them for microfaunal analyses but unfortunately the fossils were wanting due to the intense leaching of the exposed beds.

FORAMINIFERA	MONTROSE											DERRY				
	536A	536B	536C	536D	536E	536F	536G	536H	536I	543	544AB	544C	540B	540C	540D	542
Quinqueloculina bicostata d'Orbigny								x								
" byramensis Cushman								x								
" contorta d'Orbigny		x			x		x									
" limbata d'Orbigny		x														
" cf. lustra Cushman						x	x									
" seminula (Linnaeus)		x	x		x	x	x	x	x		x	x			x	x
Triloculina oblonga (Montagu) d'Orbigny						x	x									
Lenticulina cf. convergens (Bornemann)	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Dentalina catenulata (H.B.Brady)	x															
" communis d'Orbigny		x	x	x		x	x	x	x	x	x	x				x
Guttulina irregularis (d'Orbigny)	x	x	x	x	x	x	x	x	x	x	x	x		x		x
Globulina gibba d'Orbigny	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Pyrulina gutta d'Orbigny	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
" vicksburgensis (Cushman)	x	x		x	x	x	x	x			x					
Sigmomorphina cf. crassa (Roemer)	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Nonion advenum (Cushman) Cushman	x	x	x	x	x	x	x	x	x	x	x	x			x	x
" scaphum (Fichtel & Moll)				x	x	x	x		x		x	x				
Nonionella tatumi Howe	x	x	x	x	x	x	x	x	x	x		x		x	x	x
Amphidina novanum (d'Orbigny)	x		x		x	x	x	x	x	x				x	x	x
Bolivinella vicksburgensis Howe				x	x		x	x								
Buliminella elegantissma (d'Orbigny) Cushman				x			x	x		x				x	x	x
Entosolenia sp.#1 (large, sparsely pitted)	x	x	x	x		x	x	x		x	x				x	
" sp. #2 (small, smooth)	x		x	x		x	x	x			x					
Virgulina vicksburgensis Cushman																x
Bolivina depressula Cushman					x											
" mexicana Cushman	x	x														
" mississippiensis Cushman var. spatifera Cushman													x			x
" morphinvegi Cushman	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
" sp.						x										
Reussella rostimarga (Cushman)		x	x	x	x	x	x	x	x		x	x			x	x
Uvigerina sp.	x	x						x								
Spirillina limbata H.B.Brady var. bicostata Cushman					x		x									
" vicksburgensis Cushman	x															
" vivipara Ehrenberg		x														
Patellina advena Cushman								x								
Discorbis auracana (d'Orbigny)	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
" orbicularis (Terquem) Berthelin	x	x	x	x	x	x	x	x		x	x			x		x
" patelliformis (H.B.Brady) Cushman		x	x		x	x	x		x		x					
" sp.			x	x	x	x	x	x	x					x	x	x
Eponides vicksburgensis Cushman & Ellisor	x	x	x	x	x	x	x	x	x	x	x			x	x	x
Rotalia dentata Parker & Jones var. parva Cushman						x										
Asterigerina cf. bractata Cushman		x	x	x	x	x	x	x	x							
Globigerina sp.	x			x				x						x		
Anomalina mississippiensis Cushman	x					x	x			x	x		x			
Gibicides choctawensis Cushman & McGlamery	x	x	x	x	x	x	x	x	x	x		x			x	x
" lobatulus (Walker & Jacob)(d'Orbigny)		x	x	x	x	x	x	x	x		x	x				
OSTRACODA																
Pontocypris (?) mississippiensis Howe & Law							x			x						
Cytheridea (Haplocytheridea) blanpiedi Stephenson	x			x	x	x	x	x	x	x		x		x	x	x
" " sp.										x				x		x
" (Clithrocytheridea)grigsbyi Howe & Chambers var. vicksburgensis Stephenson	x	x	x		x	x	x	x	x	x						x
Cytheridea (Leptocytheridea) maguirti Stephenson					x	x	x			x				x	?	x
Exytheropteron fiski Howe & Law							x		x				x			x
Cytheretta dagyi Howe & Law		x	x				x	x		x		x		x		x
" cf. grigsbyi Howe & Chambers													x			
" rosefieldensis Howe & Law					x		x	x	x							
" thompsoni Howe & Law	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
" sp.			x					x	x	x			x	x		
Archicytheretta stephensoni Howe				x											x	
Pyricytheretta hunteri Howe & Law									x							
" sp.															x	x
Cytheridella rosefieldensis Howe & Law	x			x	x	x	x	x			x					x
" cf. vicksburgensis Howe									x	x	x	x	x	x		x
" sp.(of Howe, La. Geol. Survey, Bull. #7)																x
Buaythera woodwardensis Howe							x		x			x				
Loxoconcha woodwardensis Howe & Law	x	x						x								
" sp.						x	x							x	x	
Cytheromorpha rosefieldensis Howe & Law	x	x	x	x	x	x	x	x	x	x		x		x	x	x
" vicksburgensis Howe													x			x

FIG. 2

A complete memorandum is hereby submitted from the correspondence of T. Wayland Vaughan and Julian D. Sears.

UNITED STATES DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY, WASHINGTON, D. C.

June 23, 1938

Memorandum for Doctor Vaughan:

The mollusks in the two small lots sent in by B. W. Blanpied have been identified as follows:

Derry, Natchitoches Parish, La.

Ostrea sp.
Venericardia, cf. an undescribed species in the Mint Spring marl.
"*Chione*" *craspedonia* Dall, a species known from the Mint Spring marl and Red Bluff clay.
Mactra sp., a new species also found in the Mint Spring marl at Vicksburg, closely related to *Mactra funerata* Conrad.
Age—Vicksburg, probably Mint Spring.

Montrose, Natchitoches Parish, La.

Small fragment of *Pecten* cf. *poulsoni*. Sculpture more like that of the Mint Spring form than the Byram form.
Age—probably Vicksburg.

Signed: F. Stearns MacNeil

Dear Mr. Blanpied: I think the information you wish is given below. I have put the *Oculina* of my Eocene and Oligocene corals into a genus I have named *Archohelia*.

Sincerely yours,
Signed: T. Wayland Vaughan

Supplementary list:
Derry, Natchitoches Parish, La.
Archohelia sp.
Distal plates of a ray.
Montrose, Natchitoches Parish, La.
Archohelia sp., apparently *A. vicksburgensis* (Conrad).
Archohelia sp., small immersed calices.
Age—probably Vicksburg.

Signed: T. Wayland Vaughan

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY, WASHINGTON, D. C.

July 12, 1938

Mr. M. N. Broughton,
Paleontologist, The Texas Company,
P. O. Box 1737,
Shreveport, La.

Dear Mr. Broughton:

In reply to your letter of June 24:

The fossils which you sent, under separate cover, from near Derry, Natchitoches Parish, Louisiana, have been examined by F. Stearns MacNeil, who reports upon them as follows:

"The mollusks in the limestone sent in by M. N. Broughton of The Texas Company have been identified as follows:

Derry, Natchitoches Parish, Louisiana.
Cymbia (*Tritonopsis*) *subalveata* (Conrad)
Calyptraea sp.
Sinum sp.
Nucula sp.
Yoldia sp.

Arca sp. does not appear to be either *A. individuosa* Casey from the Red Bluff or *A. delicatula* Casey from the Mint Spring marl. Compares with an unidentified species from the upper part of the Forest Hill sand.
Atrina sp.
Modiolus sp.
Cardita aldrichi Casey
Sphaerella sp.
Cardium sp. cf. an undescribed species in the Mint Spring marl.
Chione cf. *C. craspedonia* Dall
Tellina cf. an undescribed species in the upper part of the Forest Hill sand.
Mactra cf. *M. funerata* Conrad

"Of the above species, *Cymbia subalveata* (Conrad) and *Cardita aldrichi* Casey are known only from the Mint Spring marl. *Chione craspedonia* Dall is known from the Red Bluff clay and Mint Spring marl. *Mactra funerata* is abundant in the Mint Spring marl. The *Tellina* appears to be a large, characteristic species occurring in the uppermost part of the Forest Hill sand, but which I have not yet seen in the Mint Spring marl.

"Age—lower Vicksburg, probably a horizon equivalent to either the upper part of the Forest Hill sand or the lower part of the Mint Spring marl."

The Geological Survey appreciates the gift of these fossils, and they will be added to the collections at the National Museum.

Yours very truly,
(SIGNED) Julian D. Sears
Administrative Geologist

Later, with the use of a post-hole auger, the writers penetrated below the leached zones and sampled the material at both localities.

A detailed check list was prepared on the Foraminifera and Ostracoda of the various samples, the result showing the two localities to contain essentially the same species.

The writers are of the opinion that the stratigraphic character of these exposures represents marine lentils, formed in estuarine or tidal channels indenting a fluvial deltaic plain. West of the classic locality at Rosefield, Louisiana, Fisk[3] has also noted lenticular zones within the Vicksburg, associated with a series of laminated sandy clays and smaller intercalated sand bodies.

The age of the fossils present has been determined as the equivalent of the Mint Spring marl of lower Vicksburg.

[3] H. N. Fisk, "Geology of Grant and La Salle Parishes," *Louisiana Dept. Cons. Geol. Bull.* 10 (1938), pp. 124–42.

DANGER IN REPORTING FOSSILS FAR BEYOND THEIR INDICATED RANGE AND ENVIRONMENT[1]

J. E. EATON[2]
Los Angeles, California

The science of paleontology, which attempts to record the evolution and apparent range of nearly a million kinds of animals, must necessarily have, and does have, a system for checking misidentifications. Most of the obvious errors are quickly disposed of by a critical

[1] Manuscript received, January 7, 1939.

[2] Consulting geologist, 2062 North Sycamore Avenue.

examination of the original material when this is available. Not infrequently, however, a misidentification secures such wide printed notice that it is difficult to eradicate, and impairs the work of investigators extending over many years. The writer lists here a few illustrations from California; partly in an attempt to correct the record, and partly to illustrate the advisability of more critically examining other reported instances of guide forms occurring far outside of their supposed range and environment.

Some years ago Eaton[3] listed a fauna of twenty-one species from the Upper Pliocene near Ventura, California. He included in this three poorly preserved forms, labelled *Arca* cf. *camuloensis*, *Chione* cf. *elsmerensis*, and *Pecten* cf. *healeyi*. The first two are usually considered to be guide fossils for the Lower Pliocene, and the third to be a guide for the Middle Pliocene, of California. Since these non-specific occurrences were in an uncongenial environment stratigraphically thousands of feet above the known ranges, he should have listed them as *Arca* sp., *et cetera*, instead of casting unwarranted doubt on the known occurrences and ranges.

Allied to the foregoing implication are statements, so far untraceable to any definite evidence, that the mollusk *Turritella ocoyana*, the titular head of the Temblor molluscan dynasty, ranges up into the *Valvulineria californica* zone of the overlying lower Monterey. In 15 years of collecting hundreds of faunas for micro- and macro-paleontologists the writer has never had *T. ocoyana* reported from strata equivalent to any part of the type Monterey. Most reports by others of an overlap seem to have been due to the feature that in the early days of foraminiferal research *V. californica s.s.* and several of its longer-ranged varieties were then undifferentiated. In these early days Hoots[4] reported *V. californica* from a sequence that yields *T. ocoyana* near-by. However, Hughes, who made the determination for him, informs the present writer that with later progress the form listed has turned out to be not the *sensu stricto* one, but a long-range variety common in the upper Temblor.[5] At approximately the time that the publication aforecited appeared it was rumored that some geologist had found a speciman of *T. ocoyana* lying side by side with *V. californica*. This report, apparently not put on record, presumably also involved a long-range variety of the then undifferentiated *V. californica* species.

[3] J. E. Eaton, "Divisions and Duration of the Pleistocene in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 2 (February, 1928), Table I.

[4] H. W. Hoots, "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California," *U.S. Geol. Survey Prof. Paper 165-C* (1930), p. 99.

[5] D. D. Hughes, oral communication, about 1935.

Not long ago a report was circulated that Woodring had found *Turritella ocoyana* and *Valvulineria californica s.s.* in the same bed at Palos Verdes Hills. When the paper on this district appeared the authors were careful to state that no foraminifera were found in the same region with *T. ocoyana*, and that the foraminiferal zone which it probably represented has a meager assemblage referable to either the *V. californica* zone, the zone below this, "or possibly to even somewhat older zones."[6]

It seems possible that among the hundreds of sections and thousands of Miocene samples examined each year in California some instance may ultimately be found where specimens of *Turritella ocoyana* locally held over into a basal horizon of the type Monterey, for the species is at present known to range up to within a few hundred feet of that horizon. Pending this time, in view of the hundreds of sections where an overlap has not been found, it seems advisable to examine critically unsubstantiated reports of such.

Of all the mollusks in the California Miocene, the Vaqueros guide species *Turritella inezana* is perhaps the best known and most useful. Unlike its hardier cousin *T. ocoyana*, which long existed with it and long outlived it in California, *T. inezana* is seemingly a tropical form which could stand no chill. It thrived in Vaqueros time, and at the inception of cooler waters in Temblor time departed apparently without lingering. The species has not only been a reliable guide for the Vaqueros,[7] but several of its varieties having short and overlapping ranges have provided the best basis for dividing this succession that has so far been available. Subsequent to Vaqueros time marine waters sufficiently warm for *T. inezana* apparently never returned to coastal California.

In view of the foregoing the following statement by Schenck[8] is of interest.

> The biochron of *Turritella inezana* can be extended at least to the time represented by the top of the Gould shale, according to R. M. Kleinpell (written communication), who bases the statement on specimens collected by J. Hollister and W. D. Kleinpell.

This reported occurrence of *T. inezana*, in Carrizo Plain, is approximately 5,000 feet stratigraphically above the highest known range in

[6] W. P. Woodring, M. N. Bramlette, and R. M. Kleinpell, "Miocene Stratigraphy and Paleontology of Palos Verdes Hills, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 2 (February, 1936), pp. 135 and 138.

[7] See Wayne Loel and W. H. Corey, "The Vaqueros, Lower Miocene of California," *Univ. of California Dept. Geol. Bull.*, Vol. 22, No. 3 (1932).

[8] H. G. Schenck, "What Is the Vaqueros Formation of California and Is It Oligocene?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 4 (April, 1935), footnote on p. 524.

coastal California of the tropical species, in an environment that would not only seem to be prohibitive, but which occurred after conditions had been growing more unfavorable for what must have been several million years. The present writer has worked in the particular area at intervals for eleven years, and has assisted in the collecting there of about ninety molluscan faunas from thirty-one consecutive Miocene horizons for the University of California at Los Angeles, which faunas agree with the known California range of *T. inezana*. According to Reed,[9] who was with Hollister when he collected the specimens referred to by Schenck, the form seems to have later turned out to be *T. carrisaensis*, which Reed suspected it to be, a species that superficially resembles *T. inezana*. The error, however, had secured a foothold in the literature.

In a recent book of world-wide circulation Kleinpell uses the early determination again, and makes it a basis for certain conclusions.[10]

It is only just to state that all the persons mentioned herein by name and otherwise in connection with Miocene data are among those for whose ability and devotion to research the writer has a high regard; that in the phrasing of Schenck's short notice he personally seems to detect a note of surprise, if not of polite disbelief; that he personally knows that Kleinpell originally acted on what would be considered a high single authority, and that on being informed of later developments he stated his regret that these came to his knowledge after the page proofs had been sent in.[11] On the other hand, we are faced with the hard fact that the most useful and reliable molluscan species in the California Miocene, whose apparently sharp upper limit has not been changed in a generation of intensive research, has been reported in a world-wide publication as occurring approximately 5,000 feet stratigraphically above its known range, in what would seem to be a virtually impossible environment for this tropical form.

The instances mentioned are but a few of many in California, and each province the world over presumably has a similar problem. They illustrate the need for precaution against errors, which, once these appear in the literature, are ofttimes difficult to correct. It is suggested that workers be particularly cautious about accepting the reported occurrence of any form far beyond its indicated range and environment.

[9] R. D. Reed, oral communication, summer of 1938.

[10] R. M. Kleinpell, *Miocene Stratigraphy of California* (Amer. Assoc. Petrol. Geol., 1938), pp. 73, 154–55, and Fig. 14.

[11] Written communication dated, October 8, 1938.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 254-262

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

ROCK SALT AND POTASH SALTS, GEOLOGY, BY FRANZ LOTZE

REVIEW BY R. D. REED[1]
Los Angeles, California

Steinsalz und Kalisalze, Geologie (Rock Salt and Potash Salts, Geology), by Franz Lotze. *Die wichtigsten Lagerstätten der "Nicht-Erze,"* Bd. III, Teil 1. 936 pp., 353 figs. Gebrüder Borntraeger (1938). Price: paper, RM 84; cloth, RM 87.6.

Doctor Lotze was induced by the late Professor Rinne to assist in the writing of the geological part of an elaborate discussion of salts. Upon the death of Professor Rinne, the assistant took over the entire task of writing the geological discussion and has now brought it to successful completion. A second volume to be devoted to mineralogy is being prepared by Professor Leonhardt.

In attempting to describe the salt deposits of the world in terms of their origin, Doctor Lotze proceeds first to the problems of their genesis. He treats their deposition in basins on the earth's surface, next their burial and tectonic transformation, and finally their erosion and removal by exogenous processes, which start the cycle over again. This discussion makes up the General Section; a second Special Section is devoted to a description of important deposits arranged by continents.

Doctor Lotze's large volume, devoted to the "most vivacious and temperamental of rocks," is well organized, adequately illustrated, and clearly written. It is far too elaborate to be adequately reviewed here, but because of the importance of its subject matter to many oil geologists I shall attempt to outline the major subjects it treats and to comment upon a few of the many interesting ideas and suggestions Doctor Lotze sprinkles through his pages.

The General Section, Part I, has 321 pages, 21 of which contain closely spaced references to earlier publications. Under the heading, Origin of Salt Deposits the author discusses modern salt deposits, the solutions from which they come, the conditions that control their deposition, the forms of the deposits, and other subjects. He cites many modern examples to illustrate his ideas. There follows an account of ancient salt deposits, classified stratigraphically. Because they are continental sediments, readily subject in general to solution and to metamorphism, the geologic record of their occurrence is not complete and not everywhere clear; for example, we know no demonstrably pre-Cambrian salt beds. Even the imperfect record that we possess seems to show clearly, however, that salt-forming periods have constantly alternated with relatively salt-free periods since the beginning of the Paleozoic; in fact, at one end of the series, some periods lack even gypsum, and at the other end, some periods have commercial potash deposits.

[1] The Texas Company. Manuscript received, December 12, 1938.

From such quantitative studies as he has been able to make, Doctor Lotze derives a "contemporaneity rule":

Salt deposition increases at certain times, and the increase affects large and widely separated areas.

He finds that the periods of increased salt deposition accompany and closely follow periods of strong mountain-making movements. Paleogeographic considerations suggest, furthermore, that a salt-depositing belt extending around the earth has gradually shifted from north to south since the early Paleozoic. Many of Doctor Lotze's most striking ideas about these and similar subjects may be found in briefer compass in an earlier work, "Salzabscheidung und Tektonik," which constitutes a chapter of the Stille Festschrift, reviewed in this *Bulletin*, Vol. 21 (1937), pp. 352–4.

Doctor Lotze next takes up such subjects as stratification, crystalline fabric, facies relations and changes, color, clastic inclusions, and metamorphism of salt beds. In all, he reveals keen analysis and furnishes ample citations from the published views of earlier writers. His account of salt tectonics occupies pages 204–283, with many excellent diagrams, maps, and sections. It furnishes an excellent summary of modern views on the origin and nature of salt domes. To many *Bulletin* readers these 80 pages will be of great interest and importance. In a final part of the General Section is a discussion of the denudation and solution of salt deposits. It is followed by the elaborate, 21-page bibliography already mentioned.

Part 2, the Special Section, begins with an elaborate and well illustrated summary of the salt deposits of Europe. Here will be found most of the regional data upon which have been based nearly all the better known theories ever published about the origin and nature of salt deposits. The discussion extends from page 324 to page 693, with about 120 illustrations, nearly all of which are maps and sections.

North American salt deposits are summarized in about 60 pages. Doctor Lotze believes that similar relationships of salt deposits to regional structure prevail in North America and in Europe. Whether or not his ideas prove acceptable to American workers, they will certainly be stimulating and helpful. South American salt occurrences are allotted 3 pages, African 6, Asiatic 10, and Australian one short paragraph. The desert continents seem to be cut off a bit briefly, but in the face of such a long and excellent discussion as Doctor Lotze has given us, it would be ungracious to ask for more. A page at the end is devoted to the Sea, a fluid salt deposit of such size and importance as to guarantee mankind for all time against a salt famine. Even now, according to Doctor Lotze, such salt-poor districts as California manage to secure 97 per cent of their table salt from the sea.

The closely spaced references for the special discussion occupy pages 776–824. An elaborate index fills pages 825–936, or more than 100 pages. Authors' names, fossil names, and other names are all included together, but are distinguished by three different kinds of type. If a very brief experience in using it is acceptable as a criterion, the index is highly satisfactory.

Doctor Lotze's book will prove of great interest to every geologist whose work brings him into contact with salt domes or other kinds of salt deposits. If the price were not so high, the book would probably have a wide circulation in the United States. It clearly deserves such a circulation, but 84 marks is a price to make most of us stop and think. Even with the customary 25

per cent discount to purchasers in foreign countries, which is not promised this time in the statement furnished by the publishers, the price would still seem high.

PETROLEUM DEPOSITS, BY GEORGES MACOVEI

REVIEW BY D. JEROME FISHER[1]
Chicago, Illinois

Les Gisements de Pétrole (Petroleum Deposits), by Georges Macovei. Masson et Cie, Paris (1938). 502 pp., 222 figs. 6.5×9.75 inches. Paper covers, 120 fr.

This book by the director of the Geological Institute (Survey) of Rumania and a professor at the Polytechnic School at Bucharest reminds one of Emmons' *Geology of Petroleum*. Each is divided into two parts devoted respectively to principles (161 pages in Emmons, 176 in Macovei) and to descriptions of fields (553 pages in Emmons, 282 in Macovei). Emmons allots 406 pages to fields of the United States and 7 to Rumania. Macovei describes United States fields in 37 pages and devotes 44 to Rumania. Excluding these two areas Macovei's descriptions take 201 pages, Emmons' 140. Emmons scatters his production and reserve statistics through the text, Macovei lumps his in a 5-page section at the close.

The first part of the book under review covers:

Physical and chemical properties of petroleum	—14	pages
Classification and origin of natural bitumens	—20	"
Genesis of petroleum	—37	"
Formation of petroleum deposits	—44	"
Structure of same	—23	"
Exploitation, evaluation, waste and loss	—29	"
Prospecting	— 9	"

No doubt this volume will be of great value in colleges and institutes where the teaching is in French. Others will find it a useful summary of certain continental ideas, particularly those of Mrazec. It is up-to-date and is well illustrated with numerous maps and cross sections. The United States map (p. 389) shows no fields in Michigan, though these are described later (pp. 397–9). Some seem to favor replacing *Bibi Eibat* with *Stalin* (p. 316), but as yet Mussolini and Hitler are apparently not so honored. Possibly the latter has hopes of supplanting *Baicoi* or *Bustenari*.

[1] University of Chicago. Manuscript received, January 2, 1939.

MANUAL OF SEDIMENTARY PETROGRAPHY BY W. C. KRUMBEIN AND F. J. PETTIJOHN

REVIEW BY PARKER D. TRASK[1]
Washington, D.C.

Manual of Sedimentary Petrography, by W. C. Krumbein and F. J. Pettijohn. xiv plus 549 pp., 265 figs., 53 tables. 6×9 inches. Cloth. D. Appleton-Century Company, New York, (1938). Price, $6.50.

This book is a comprehensive summary of the means of studying sediments in the laboratoy. It is divided in two equal parts, the first by Krumbein

[1] United States Geological Survey. Manuscript received, January 12, 1939.

on mechanical analyses, and the second by Pettijohn on the petrology and other aspects of sediments. The book begins with an account of collecting and preparing samples for analysis and then launches upon an extensive discussion of mechanical analyses and the ways of presenting the results of such analyses. The approach to the problem is rigorously mathematical and on the whole is comprehensive and reliable, though on pages 240 and following, it might have been better to use the geometric instead of the arithmetic mean in calculating m. As statistical methods are very suitable for the study of the mechanical composition of sediments, a general account of statistical methods is included. The section on the mechanical investigation of sediments concludes with a discussion of statistical methods of studying the orientation of mineral and rock fragments, which should prove helpful to students of igneous and metamorphic rocks, as well as those who investigate sediments.

The second part of the book begins with a description of quantitative methods of studying the shape, roundness, and surface textures of the constituents of sediments. Following this is a discussion of the petrologic investigation of sediments. Among the subjects treated are: preparation of sample, means of separating heavy minerals, mounting of specimens, optical methods, descriptions of minerals found in sedimentary rocks, and means of presenting results of petrologic studies. The section on optical methods is brief and according to the author is included only for the purpose of making the book self-contained. The chapter on description of minerals contains petrologic data on about 60 minerals found in sedimentary rocks. The description of each individual mineral is accompanied by a few remarks on the diagnostic features for recognizing the particular minerals. In addition, most of the descriptions are illustrated by line drawings which show the common habits and cleavage of the minerals. Following the description of the individual minerals are several tables which classify minerals according to common properties. After the description of the minerals come chapters on chemical methods of study and on mass properties of sediments, such as color, specific gravity, porosity, permeability, and plasticity. The volume concludes with an account of laboratory equipment and organization of work. The book contains relatively few examples of the application of laboratory study of sediments to industry and to field problems.

This volume unquestionably fills a definite need in the investigation of sediments. The advance in the study of means of presentation of the results of mechanical analysis during the past 10 years has been so pronounced that it is particularly pertinent at this time to take stock of the present status of the subject. The chapters on statistical methods, as applied to geology and particularly to sediments, are a most welcome contribution. The section on means of making mechanical analyses likewise is worth while, but in the last few years it has been covered adequately by several other writers, notably Gessner, Gripenberg, and Rubey.

The second part, which deals mainly with petrologic studies, seems somewhat less comprehensive than the first part. However, though some subjects, such as the study of clays and the stability of immersion liquids, do not seem to have been treated particularly fully, nevertheless, practically all phases of sedimentary petrology that a student might want to consider are mentioned and the discussion of each subject is supplemented by references to the key literature.

The citations are given as footnotes rather than in lists at the end of chapters, with the result that sometimes it may be necessary to consult the authors' index at the end of the book in order to find desired citations. The references to the literature are unusually comprehensive, as more than 500 names are given in the list of authors cited. The subject index contains about 1,000 titles, which perhaps is inadequate for a book of such comprehensive scope. The general typography is excellent and the numerous illustrations are very well done.

The book is designed as a manual or textbook. The second part certainly achieves this purpose. It is well balanced, written in simple style, and on the whole probably will be more appreciated by geologists than the first part, which impresses the reviewer as a lengthy essay dedicated to specialists in methodology. As a scientific contribution, this first part is good, particularly because of the new contributions to knowledge it contains; but as a text book it may be somewhat less effective. The language is highly technical and a good grasp of mathematics and physics is needed to understand it. Moreover, many minor points seem to be unduly emphasized, with the result that readers unfamiliar with the subject may have difficulty in ascertaining what is essential and what is not.

The volume, despite the abstruseness of the first part, however, is a valuable aid to the study of sediments. Practically every subject a person needs to consider in the laboratory investigation of sediments is mentioned, and, with patience and with the aid of some of the references, he can find almost anything he requires.

RECENT PUBLICATIONS

AFGHANISTAN

*"Notes on the Structure of the Hindou-Kouch," by H. de Cizancourt, with the collaboration of Mme. H. de Cizancourt and H. Vautrin. *Bull. Soc. Geol. France*, 5th Ser., Vol. 7, No. 7 (1937) (Paris, April, 1938), pp. 377–400; 2 figs. In French.

ARGENTINA

*"La observación y la fotografía aéreas en la búsqueda de petróleo" (Aerial Photography in Petroleum Exploration), by Enrique Fossa-Mancini. *Bol. Inform. Petrol.*, Vol. 15, No. 169 (Buenos Aires, September, 1938), pp. 51–102; 16 figs. (14 photographs).

ARIZONA

**The Oil Possibilities of Arizona*, by D. A. Holm. Arizona State Land Dept., Phoenix (December, 1938). 58 mimeographed pp., 2 figs. 8.5×11 inches. Paper cover. Contains bibliography of 33 titles, descriptive list of oil seeps, and partial list of wells.

BULGARIA

*"Indications of Petroleum in the Coastal Region South of Burgas," by Hans-Joachim Fabian. *Petrol Zeit.*, Vol. 34, No. 48 (Vienna, December, 1938), pp. 3–4; 2 photographs. In German.

CALIFORNIA

*"General Report on Wilmington Oil Field, California," by A. W. Nash. *California Oil World*, Vol. 31, No. 24 (Los Angeles, December, 1938), pp. 2–12; 6 illustrations.

*"San Andreas Rift in Southwestern California," by Bailey Willis. *Jour. Geol.*, Vol. 46, No. 8 (Chicago, Illinois, November-December, 1938), pp. 1017–57; 2 sketch maps, 2 photographs.

CZECHOSLOVAKIA

*"Special Meeting of the Geological Society of France in Czechoslovakia (Central Bohemia), September 21–29, 1936." *Bull. Soc. Geol. France*, 5th Ser., Vol. 7, No. 8 (Paris, 1937). Published by the Society, 28 rue Serpente, VI (April, 1938). 6 papers by 6 authors, with introduction by F. Blondel: "Two Geological Sections through the Western Carpathians," by Dimitrij Andrusov; "Stratigraphy and Parellelism of the Lower Ordovician of Bohemia," by Bedrich Boucek; "Tectonic Evolution of the Barrandien (Lower Silurian of Barrande)," by Radim Kettner; "The Tremadocien and Lower Arenigien [Ordovician] in Bohemia," by Jan Koliha; "Petrology of the Eruptive Massif of Central Bohemia," by Alexandr Orlov; " 'Colonies of Barrande'," by Jaroslav Perner; "Volcanic Activity in the Barrandien," by Frantisek Slavik; "The Crystalline Rocks of the Czechoslovakian Carpathians," by Vladimir Zoubek. In French.

FLORIDA

*"Status of Exploration in Florida Not Conclusive," by Paul Thomas. *Oil Weekly*, Vol. 92, No. 3 (Houston, December 26, 1938), pp. 42–44, 2 figs., including table of Tertiary and Upper Cretaceous formations.

FRANCE

*"Pechelbronn France's Successful Oil Mining Enterprise," by Charles E. Chambers. *World Petrol.* (New York), Vol. 9, No. 13 (December, 1938), pp. 46–48; 8 photographs.

*"Possibilities of Petroleum Exploration in Northern and Northeastern France," by Paul Fallot and P. Pruvost. *Annal. Combus. Liquides*, No. 3 (Paris, May–June, 1938), pp. 439–58; 2 figs., 6 pls. In French.

GENERAL

**Report of the Committee on the Measurement of Geologic Time, 1937–1938*, by Alfred C. Lane, chairman, *et al. National Research Council*, 2101 Constitution Avenue, Washington, D.C. (October, 1938). Chairman's report and 12 supplementary reports. 123 pp. Mimeographed. 8.25×10.75 inches. Paper cover.

*"Stratigraphic vs. Structural Prospecting," by E. E. Rosaire. *Oil and Gas Jour.*, Vol. 37, No. 32 (Tulsa, December 22, 1938), pp. 43–56; 10 illustrations.

**Bibliography of Geological Sciences*, Vol. 8 (1937). Published by the Geological Society of France with the assistance of the French Society of Mineralogy. 338 pp. In French. Titles listed alphabetically by authors grouped in 19 sciences. Stratigraphy contains 659 titles; Paleontology, 867; Tectonics,

122; Mineral Resources and Economic Geology, 508. Total titles: 4,753. 6.5×10 inches. Paper cover. Société Géologique de France, 28, rue Serpente (VIe), Paris (February 1, 1938). Price, 100 fr.

Manual of Sedimentary Petrography, by W. C. Krumbein and F. J. Pettijohn. The Century Earth Science Series, edited by Kirtley F. Mather. Part I, "Sampling, Preparation for Analysis, Mechanical Analysis, and Statistical Analysis," by Krumbein. Part II, "Shape Analysis, Mineralogical Analysis, Chemical Analysis, and Mass Properties," by Pettijohn. 549 pp., 265 figs. 6×9 inches. Cloth. D. Appleton-Century Company, 35 West 32nd Street, New York (1938). Price, $6.50.

Compte rendu du deuxième Congrès pour l'avancement des études de Stratigraphie Carbonifère (Report of the Second Congress for the Advancement of the Study of Carboniferous Stratigraphy, Heerlen, 1935). 71 papers by 59 authors. Edited by W. J. Jongmans. 3 vols., 1743 pp., 155 pls., 700 photographs (225 of American fossil plants). "An encyclopedia of knowledge of the Carboniferous of the world." Published by Gebrüder van Aelst, O. L. Vrouwe Kade 10–11, Maastricht, Nederland (1937–1938). Price, postpaid, in Dutch Fl., 52.50 (Approx. $30); clothbound, Fl. 61.50. If the volume of the first congress (1927) and the 3 volumes of the second congress (1935) are purchased together: Fl. 64; cloth, Fl. 78.

*"Abstracts of Papers to be Offered at the Fifty-First Annual Meeting, December 28–30, 1938." *Bull. Geol. Soc. America*, Vol. 49, No. 12, Pt. 2 (419 West 117th Street, New York, December 1, 1938), pp. 1863–1966. Abstracts: the Geological Society of America; the Paleontological Society; the Seismological Society of America, Eastern Section; Section E, June and December meetings.

"Lexicon of Geologic Names of the United States (including Alaska)," by Grace M. Wilmarth. *U. S. Geol. Survey Bull. 896* (1938). Part 1, A–L, pp. 1–1244; Part 2, M–Z, pp. 1245–2396. Supt. of Documents, Gov't Printing Office, Washington, D.C. Price, $2.50 for the set.

Oil Shale and Cannel Coal. Proceedings of a Conference Held in Scotland, June, 1938. 473 pp. Illus. 35 articles, by many authors. 6×9 inches. Cloth. The Institute of Petroleum, The Adelphi, London, W.C.2. Price, 30 sh.

GEOPHYSICS

*"Five Billion Barrels Geophysically Discovered at Cost of $100,000,000," by V. G. Gabriel. *World Petrol.* (New York), Vol. 9, No. 13 (December, 1938), pp. 34–42; 12 photographs; table showing fields of Gulf Coast discovered by geophysics.

*"Utilitarian Aspects of Geophysics," by A. G. McNish. *Sci. Monthly* (Science Press, Grand Central Terminal, New York City), Vol. 46 (June, 1938), pp. 495–507; 9 photographs.

GERMANY

*"Revision of the Invertebrate Fauna of the Upper Silesian Trias," by Paul Assman, with "A Contribution on the Sponges," by Hermann Rauff. *Abh. Preussischen Geol. Landesanstalt*, New Ser., Vol. 170 (Berlin, 1937). 134 pp., 22 pls. of fossils. Approx. 7×10 inches. Paper cover. Price, RM 15. In German.

*"Investigations of Cyclic Sedimentation of Geosynclinal and Epi-Con-

tinental Areas," by K. Fiege. *Ibid.*, Vol. 177. 218 pp., 23 figs., 10 pls. In German.

*"Stratigraphy and Paleontology of the Wocklum Beds (Upper Devonian)," by Otto H. Schindewolf. *Ibid.*, Vol. 178. 132 pp., 27 figs., 4 pls. Price, RM 5. In German.

*"Transgression of the Visé [Mississippian] on the North Border of the Rhenish Schiefergebirge," by Henry Paul. *Ibid.*, Vol. 179. 117 pp., 4 figs., 1 pl., 1 table. Price, RM 4. In German.

*"The Buntsandstein Region between Kulmbach and Bayreuth," by Hans Steinlein. *Ibid.*, Vol. 180. 90 pp., 1 fig., 2 pls. In German.

*"The German Zechstein Brachiopods," by Erich Malzahn. *Ibid.*, Vol. 185. 77 pp., 6 figs., 4 pls. Price, RM 3. In German.

ILLINOIS

"Oil and Gas Development Map of the Fairfield Area (Ts. 1–3 S., Rs. 6–8 E.), Aden and North Aden Fields," *Illinois Geol. Survey* (December, 1938). Blue-line print. Order from map agent, 305 Ceramics Building, Urbana. Price, $0.60.

"Oil and Gas Development Map of the Kinmundy Area (Ts. 4–6 N., Rs. 3–5 E.), St. James Field." *Ibid.*

IOWA-MISSOURI

*"Geologic Aspects of the Forest City Basin," by W. G. Osborn. *Oil and Gas Jour.*, Vol. 37, No. 34 (Tulsa, January 5, 1939), pp. 12–13, 22; 2 figs., 1 photograph.

KANSAS

*"Truncated Structures Cause Phenomenal Recoveries in Western Kansas," by Joseph A. Kornfeld. *Oil Weekly*, Vol. 92, No. 3 (Houston, December 26, 1938), pp. 36–38; 1 photograph and table of truncated structures.

*"Bibliography of Kansas Geology (1823–1938)," by Walter A. Ver Wiebe and Byron N. Cooper. *Bull. Municipal Univ. Wichita*, Vol. 13, No. 11 (November, 1938). *Univ. Studies Bull. 5* (Wichita, Kansas). 76 pp. 5.75×8.25 inches. Paper cover.

MID-CONTINENT

Map of Mid-Continent States and Adjacent Areas, Showing Oil and Gas Fields and Their Location in Relation to Age and Position of Surface Rocks. 72×54 inches. In colors. Geo. F. Kelly, Box 1773, Tulsa, Oklahoma (1938). Price: plain paper, $16.00; cloth, $20; dissected mounting, $22.50.

OHIO AND GREAT LAKES REGION

*"The Fauna of the Typical Olentangy Shale," by Clinton R. Stauffer. *Jour. Geol.*, Vol. 46, No. 8 (Chicago, Illinois, November-December, 1938), pp. 1075–78.

OKLAHOMA

**Tulsa Geological Society Digest.* Edited by R. V. Hollingsworth. Abstracts of papers read at the semi-monthly meetings in 1938, published by the Society. Copies of this and previous issues may be purchased from M. H. Brown, secretary-treasurer, Darby Petroleum Corporation, Philtower Building, Tulsa. 41 pp. 6×9 inches. Paper cover. Price, $0.50.

TEXAS

*"Stratigraphy and Structure of the Malone Mountains, Texas," by Claude C. Albritton, Jr. *Bull. Geol. Soc. America*, Vol. 49, No. 12, Pt. 1 (New York, December 1, 1938), pp. 1747–1806; 19 pls., 5 figs., 1 table.

*"Crude Oil Reserves of Texas Panhandle," by Henry Rogatz. *Oil Weekly*, Vol. 92, No. 4 (Houston, January 2, 1939); pp. 17–20. Includes "Subsurface Geological Map of Texas Panhandle Oil and Gas Field," on a folded sheet approx. 24×38 inches, in colors.

Oil wells on Capitol Plaza, Oklahoma City.

The twenty-fourth annual meeting of the Association will be held at Oklahoma City, March 22–24, 1939.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 263-269

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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TWENTY-FOURTH ANNUAL MEETING, OKLAHOMA CITY, MARCH 22–24, 1939

GENERAL COMMITTEE

R. W. Laughlin, general chairman, Laughlin-Simmons and Company, Box 383, Oklahoma City
J. T. Richards, chairman in charge of technical program, Gulf Oil Corporation, Box 1557, Oklahoma City
John E. Van Dall, chairman in charge of arrangements, Magnolia Petroleum Corporation, Box 1828, Oklahoma City

COMMITTEE CHAIRMEN

Entertainment: Jerry B. Newby, consultant, 1816 N.W. 23rd Street
Ladies: William H. Atkinson, consultant, Ramsey Tower
Diner-Dance: Dan O. Howard, Oklahoma Corporation Commission
Finance: Bob Hancock, Magnolia Petroleum Corporation, Box 1828
Publicity: Richard W. Camp, Consolidated Gas Utilities Corporation, Hales Building
Technical: E. A. Paschal, Coline Oil Company, 1012 Tradesmen's National Bank Building
Field Trips: Robert H. Dott, Oklahoma Geological Survey, Norman, Oklahoma
Golf: Roy Dale Jones, Ardie Oil and Gas Company, 342 Key Building
Reception-Registration: D. A. McGee, Kerlyn Oil Company, 2009 First National Building
Exhibits: I. Curtis Hicks, First National Bank Building

The twenty-fourth annual meeting of the Association will be held in Oklahoma City, Oklahoma, March 22, 23, and 24, 1939. The Oklahoma City Geological Society, together with the geologists in the West Oklahoma District, cordially invite all members of the Association, their wives, and friends. The Skirvin Hotel is convention headquarters. The thirteenth annual meeting of the Society of Economic Paleontologists and Mineralogists will be held also at the Skirvin, March 23 and 24. The tenth annual meeting of the Society of Exploration Geophysicists will be held at the Huckins Hotel, March 21, 22, and 23.

Pre-convention.—On Tuesday, March 21, the day preceding the general technical program, the registration counter will be open, and various committees will be in session. The annual meeting of the business committee, which is composed of the members of the executive committee, the district representatives, and the division representatives, convenes at 2:00 P.M., Tuesday, at the Skirvin. Also on Tuesday, the scientific exhibits will be in place.

The meeting of the research committee, A. I. Levorsen, chairman, is of particular interest on Tuesday. An informal dinner of the committee, and any others who may be interested, is scheduled at 6:30 P.M., in the Skirvin Hotel. This will be followed by the annual open meeting of the committee. The topic for discussion is "The Tectonic Map of the United States."

Registration.—Members and guests are urged to register in the Skirvin Tower Hotel as soon as possible after securing their hotel accommodations. Early registration will better enable the committees in charge to arrange entertainment, field trips, and golf. There will be no registration fee. All persons desiring further information on registration-reception should write D. A. McGee, 2009 First National Building, Oklahoma City, Oklahoma.

Field trips.—1. A pre-convention field trip has been scheduled to study the Permian. It will assemble at Sayre, Oklahoma, Sunday night, March 19, and end on Tuesday, March 21, at Oklahoma City.

2. Charles E. Decker, of the University of Oklahoma, will conduct a one-day field trip for a bird's-eye view of the Arbuckle Mountains and the Ardmore basin, Saturday, March 25.

The stratigraphy of the Paleozoic rocks and the structural features along and adjacent to U. S. Highway 77 will be featured.

The cost of all field trips will be prorated and paid by each person attending. Registration will be at the convention registration desk. All persons desiring further information should communicate with Robert H. Dott, Oklahoma Geological Survey, Norman, Oklahoma.

Technical papers.—The technical program includes a wide variety of interesting, timely papers, assuring universal appeal. Papers will be grouped and presented according to geologic provinces, in the main, and on a definite time schedule. In response to popular demand, ample time for discussion has been allowed and members are urged to prepare themselves to discuss papers of interest to them. One session will be devoted to the economic aspects of our profession and industry, including brief, concise reports of new developments during the past year. Arrangement and presentation of papers will be supervised by the following sub-chairmen of the program committee.

General session (Wednesday A.M., March 22), J. T. Richards, Box 1557, Oklahoma City, Oklahoma
Permian basin (Wednesday P.M., March 22), Ronald K. DeFord, Box 865, Midland, Texas
Mid-Continent-Pennsylvanian (Thursday A.M., March 23), N. W. Bass, Box 311, Tulsa, Oklahoma
Economics and Recent Development (Thursday P.M., March 23), R. J. Riggs, Box 591, Tulsa, Oklahoma
Mississippi embayment (Friday A.M., March 24), Perry Olcott, Box 2180, Houston, Texas
North-Central states (Friday P.M., March 24), A. H. Bell, 305 Ceramics Building, Urbana, Illinois

Titles and abstracts of papers to be included in the printed program should be sent immediately to the designated chairmen. Paleontological and mineralogical subjects should be sent to C. G. Lalicker, Geological Department, University of Oklahoma, Norman, Oklahoma.

Golf.—The golf tournament for the J. Wallace Bostick cup will be held at the Oklahoma City Golf and Country Club, Thursday, March 23. Names and handicaps or average scores for 18 holes should be turned in at the registration desk or mailed to Roy Dale Jones, 2612 First National Bank Building, Oklahoma City, Oklahoma. Green fees will be $2.00.

Ladies entertainment.—A get-acquainted and renew-friendship tea will be held at the Oklahoma Club from 3:00 P.M. to 5:00 P.M., Wednesday, March 22.

A play portrayal, by Mrs. Madeline Douglas Bullard, is arranged for Thursday, 2:00 P.M., March 23, at the Y.W.C.A.

Banquet and dance.—A banquet will be held in the Silver Glade Room of the Skirvin Tower Hotel, Thursday, March 23, at 7:30 P.M., followed by dancing. The charge per plate, including dancing, will be $2.50, plus tax.

Hotels.—Your room reservation should be made by you at once, directly to the hotel of your choice. It is usually wise to indicate a second and third choice, so your reservation may be passed on in the event the first hotel is unable to accommodate you. Ask for confirmation of your reservation. Members having difficulty in securing accommodations may communicate with the chairman of the registration-reception committee.

The Skirvin Tower Hotel, where the convention registration, technical sessions, and exhibits are held, is across the street from the Skirvin Hotel; the two are under the same management and connected with an underground passage.

HOTELS AND RATES

Hotel and Blocks from Headquarters		*Rooms*	*Without Bath*		*With Bath or Shower*	
			Single	*Double*	*Single*	*Double*
Skirvin	Hdqtrs.	450			$3.00–$4.00	$3.50–$6.00
Biltmore	4	600			2.50– 5.00	3.50– 6.00
Black	5	200			2.50– 3.00	3.50– 4.00
Huckins	1	265			2.50–Up	3.50–Up
Kingkade	2	225			2.00– 2.50	3.00– 3.50
Park-O-Tell	30	90			2.50– 3.00	3.00– 4.00*
Sieber Hotel and Apts.	14	60			2.00–Up	3.00–Up
Travelers	4	50	$1.00–$1.50	$1.50–$2.00	1.50– 2.00	2.00– 3.00
Wells-Roberts	1	200			2.00– 3.00	3.00– 4.00

* Includes garage accommodations.

Photographs.—Individual photographs of members are desired for Association records. All members are urged to present themselves at the studios of W. Ward Clark, mezzanine floor, Skirvin Tower Hotel, where their photographs will be made at their convenience. This arrangement, with the compliments of the convention photographer, provides the Association with a copy of the photograph. The member is under no obligation.

General.—Oklahoma City is centrally located for most of our members and friends in the Mid-Continent and it is also midway between New York and California. A large attendance is expected. You should make your arrangements immediately if you have not already made them. Additional information will be supplied by John E. Van Dall, chairman in charge of arrangements, Box 1828, Oklahoma City, or by any member of the local committee.

PRELIMINARY LIST OF TECHNICAL PAPERS

DONALD C. BARTON, Humble Oil and Refining Company, Houston (presidential address): Correlation of Crude Oil with Special Reference to the Gulf Coast

E. H. SELLARDS, University of Texas Bureau of Economic Geology, Austin (presidential address, Society of Economic Paleontologists and Mineralogists): Some Vertebrate Fossils of the Texas Gulf Coastal Plain

F. M. KANNENSTINE, Independent Exploration Company, Houston, Texas: Relation of Geophysics and Geology

W. H. TWENHOFEL, University of Wisconsin, Madison: The Problem of Origin of Black Shales

CARL O. DUNBAR, Yale University, New Haven, Connecticut: Type Permian of Russia and Permian of the World

VAUGHN W. RUSSOM and JOSEPH H. MCCOY, Sinclair Prairie Oil Company, Chickasha, Oklahoma: Stratigraphy and Surface Geology of the Anadarko Basin Region

SHERWOOD BUCKSTAFF, Shell Petroleum Corporation, Tulsa, Oklahoma: The Permian of Oklahoma

GEO. H. NORTON, Atlantic Refining Company, Wichita, Kansas: Permian Red Beds of Kansas

F. P. SHEPARD, Scripps Institution of Oceanography, La Jolla, California: Recent Studies of the Ocean Floor off California

SIDNEY SWENSRUD, assistant to the president, Standard Oil Company of Ohio, Cleveland: The Relation between Crude Oil and Product Prices

WALLACE E. PRATT, vice-president, Standard Oil Company of New Jersey, New York City: The Basis for Proration in Texas

ROBERT H. Dott, director, Oklahoma Geological Survey, Norman: Regional Geology of Oklahoma

IRA H. CRAM, The Pure Oil Company, Tulsa, Oklahoma: Regional Structure of the Mid-Continent Area

H. S. MCQUEEN, Missouri Geological Survey, Rolla: Geology of the Forest City Basin

L. E. WORKMAN, Illinois State Geological Survey, Urbana: Subsurface Geology of the Chester Series in Illinois

N. W. BASS, U. S. Geological Survey, Tulsa, Oklahoma, H. M. SMITH, U. S. Bureau of Mines, Bartlesville, Oklahoma, *et al.*: Relationship of Oils from the Mississippi Lime and the Shoestring Sands of the Cherokee Shale in Osage County, Oklahoma, and a Part of Southeastern Kansas

F. W. ROLSHAUSEN, Humble Oil and Refining Company, Houston, Texas: Source of Gulf Coast Sediments

W. M. COGEN, Shell Oil Company, Houston: Heavy Minerals

J. BRIAN EBY, consultant, Houston, and M. T. HALBOUTY, Merit Oil Corporation, Houston: The Relationship between Geophysics and Gulf Coast Salt Domes

JOHN C. POOLE, Corpus Christi, Texas: Geology of the Saxet Pool

ED. HAMNER, Humble Oil and Refining Company, Genoa, Texas: Geology of the Amelia Field

CHARLES E. DECKER, University of Oklahoma, Norman: Basal Sedimentary Formations in the Wichita Mountains

CHARLES E. DECKER: Carbonaceous and Asphaltic Material in the Lower Arbuckle Limestones of the Wichita Mountains

RECENT DEVELOPMENTS

Oklahoma: E. F. SHEA, Stanolind Oil and Gas Company, Tulsa

Kansas: RYCROFT G. MOSS, Phillips Petroleum Corporation, Wichita

Illinois: A. H. BELL, Illinois Geological Survey, Urbana

West Texas-New Mexico: HAL P. BYBEE, University of Texas, Austin, and BERTE R. HAIGH, University Lands, Midland, Texas

Southwest Texas: GENTRY KIDD, Stanolind Oil and Gas Company, San Antonio

California: HAROLD W. HOOTS, Richfield Oil Corporation, Los Angeles

Rocky Mountains: J. M. KIRBY, The California Company, Denver, Colorado

North Louisiana–South Arkansas: W. C. SPOONER, consultant, Shreveport, Louisiana

Louisiana and Texas Gulf Coast: O. L. BRACE, consultant, Houston

North-Central Texas: ROBERT ROTH, Humble Oil and Refining Company, Wichita Falls

Foreign: BASIL B. ZAVOICO, The Chase National Bank, Houston, Texas

S.E.P.M. PAPERS

FLAVY E. DAVIS, paleontologist, Gulf Oil Corporation, Houston, Texas: Some Species of Textularia from the Tertiary of Texas

A. C. ELLISOR, research geologist, Humble Oil and Refining Company, Houston, Texas: Correlation of the Zones of the Miocene of South Louisiana

J. B. GARRETT, paleontologist, Stanolind Oil and Gas Company, Houston, Texas: Some Middle Tertiary Smaller Foraminifera from Subsurface Beds of Chambers County, Texas

MARCUS A. HANNA and DONALD W. GRAVELL, paleontologists, Gulf Oil Corporation, Houston, Texas: Some New Species of Larger Foraminifera from the Claiborne of Mississippi

NORMAN D. NEWELL, J. BROOKES KNIGHT, RAYMOND C. MOORE, and KENNETH BRILL: Invertebrate Fauna of the Permian Whitehorse Sandstone

CHARLES E. DECKER, professor of paleontology, University of Oklahoma, Norman, and EDWARD A. FREDERICKSON, graduate student, University of Wisconsin, Madison: A New Graptolite Horizon in Wisconsin

CHARLES E. DECKER, presented by permission of the Oklahoma Geological Survey: *Didymograptus protobifidus* in North America

A. K. MILLER and W. M. FURNISH, University of Iowa, Iowa City: Permian Ammonoid Zones

HELEN TAPPAN, graduate student, University of Oklahoma, Norman: Foraminifera from the Grayson Formation of Northern Texas

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 270-271

RESEARCH NOTES

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(Members' terms expire immediately after annual Association meetings of the years shown)

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The purpose of the research committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the research committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

RESEARCH COMMITTEE AT OKLAHOMA CITY, MARCH, 1939

The subject for the annual round-table discussion of the research committee to be held on the evening of March 21, at the annual meeting of the Association at Oklahoma City, is "The Tectonic Map of the United States." This is a map which has been in the process of compilation for nearly 5 years by the committee on tectonics of the National Research Council. This committee consists of the following members.

C. R. Longwell, chairman
P. B. King, vice-chairman
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William Bowie
Walter H. Bucher
Eugene Callaghan
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A. C. Waters
Eldred Wilson

Each of the committee members was assigned a specific area in the United States and asked to compile the structure of this area. Wherever possible the structure is in the form of contours and the contours on varying horizons will be in various colors. The project at present is nearing completion and each of the members has submitted his structure map and the final compilation will be commenced this year. It is planned to have the structure maps of each of these regions put onto lantern slides so that they can be projected on a large scale, and it is hoped that this will stimulate considerable thought and discussion on the problems on regional structure within the United States. In addition, photostat copies of the maps will be available during the meeting so that corrections may be added by any of our members who have the

necessary information to the end that when the final map is published it will be as nearly correct as possible. The final map will be published on the same scale (1:2,500,000) which was used on the geological map of the United States published by the United States Geological Survey.

As has been the custom, the round-table discussion will be preceded by a dinner, the details of which will be announced later.

A. I. LEVORSEN, chairman

TULSA, OKLAHOMA
JANUARY 16, 1939

Air view of Oklahoma City.

The twenty-fourth annual meeting of the Association will be held in Oklahoma City, March 22–24, 1939.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 272-273

Memorial

LOZELL CHARLES HOOKWAY
1905–1938

The death of Lozell Charles Hookway on November 19, 1938, took from the ranks of petroleum geologists one of its most congenial personalities, and one who, although relatively young in years, had made rapid strides in his chosen profession by virtue of his ability.

His death came by drowning while duck hunting on Humes Lake, near Athens, Texas, with three companions, S. A. Germany, R. M. Trowbridge, and J. R. Wise, all of Tyler, Texas. While rowing out to a duck blind, Hookway, Trowbridge, and Wise were suddenly plunged into the lake when their small boat capsized. Hookway attempted to swim to the security of the blind, but his heavy clothing, which included an ammunition-laden hunting coat and hip boots, proved to be too great an impediment in the cold water. Germany, who previously had been transported to the blind, witnessed the accident and seeing that Hookway was in serious difficulty, immediately stripped off his clothing and dived into the lake. However, Hookway had gone below the surface and despite repeated valiant efforts, Germany was unable to rescue his companion. Trowbridge and Wise were ultimately successful in extricating themselves from their own predicament.

Hookway was born, February 8, 1905, in the town of Grass Lake, Michigan, the son of Mr. and Mrs. Charles E. Hookway. His schooling in the geological sciences was obtained at the California Institute of Technology, where he earned a bachelor of science degree in geology in 1929.

In October, 1929, he began his geological career as assistant to W. M. Nicholls of San Antonio, Texas, and continued in this capacity until September, 1931. He became a member of the American Association of Petroleum Geologists in 1930.

From April, 1932, to April, 1934, he was in charge of a field party collecting Tertiary vertebrate fauna in southern California for the California Institute of Technology.

He joined the staff of the Magnolia Petroleum Company as assistant geologist at Wichita Falls, Texas, in April, 1934. A year later he was transferred to Amarillo, Texas, as geologist. In January, 1936, he returned to Wichita Falls, this time in the capacity of district geologist. At the time of his death he was serving as district geologist at Tyler, Texas, having taken over this assignment in June, 1937.

He is survived by his devoted wife, Hazel Hawthorn Hookway; his parents, who reside in Arcadia, California; and a step-brother, F. Raymond of Pasadena, California.

Charles possessed a delightful sense of humor, a ready smile, and an inherent congeniality which made for him a widespread group of friends, both in and out of his profession. He had developed the rare capacity of thorough application to work when work was to be done, coupled with the ability to divert his whole thought to recreation when time for recreation had come.

It is perhaps paradoxical that his death should have come while engaged in a sport associated with the out-of-door life to which he had been devoted since boyhood.

Those of us who knew him best realize how inadequate the written or spoken word is to express our true and inner feeling of this loss, and to define fully the magnitude of the void created by the departure of our colleague and friend.

C. L. HEROLD

HOUSTON, TEXAS
December 14, 1938

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 2 (FEBRUARY, 1939), PP. 274-280

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Newly elected officers of the Dallas Petroleum Geologists at Dallas, Texas, are: president, R. E. RETTGER, Sun Oil Company; vice-president, W. W. CLAWSON, Magnolia Petroleum Company; secretary-treasurer, R. J. FORSYTH, Seaboard Oil Company.

MARK C. MALAMPHY, Cumberland, Maryland, of the firm of Hans Lundberg, Ltd., is specializing on the geophysical problems of the Appalachian Mountains.

ERNEST R. LILLEY, professor of economic geology at New York University, is chairman of the committee of the *Annotated Bibliography of Economic Geology* succeeding WALDEMAR LINDGREN who was chairman for the first 10 volumes of the Bibliography.

The Society of Economic Geologists held its annual meeting with the Mining Geology Section of the American Institute of Mining and Metallurgical Engineers at the annual meeting of the Institute at New York City, February 13–16. The Society of Economic Geologists held an informal meeting with the Geological Society of America at the latter's 50th anniversary in New York, December 28–30, 1938.

W. F. Fulton, of the Union Producing Company, Houston, Texas, spoke on "Determination of Phase Relation under Reservoir Conditions in Gas and Distillate Fields," before the noon meeting of the Houston Geological Society, December 15.

GEORGE W. LA PEIRE has opened a consulting office for geological advice at 4105 West Main Street, Belleville, Illinois.

The Kansas Geological Society, of Wichita, Kansas, has elected the following officers for 1939: president, GEORGE H. NORTON, Atlantic Refining Company; vice-president, THOMAS H. ALLAN, consulting geologist; secretary-treasurer, E. GAIL CARPENTER, consulting geologist and operator; directors, PHIL K. COCHRAN, Carter Oil Company, and R. G. MOSS, Phillips Petroleum Company.

New officers of the Appalachian Geological Society, Charleston, West Virginia, are: president, ROBERT C. LAFFERTY (re-elected), of the Owens, Libbey-Owens Gas Department, Charleston, West Virginia; vice-president, J. R. LOCKETT, of the Ohio Fuel Gas Company, Columbus, Ohio; vice-president for the southern district, P. E. DEUFENDACH, of the Kentucky-West Virginia Gas Company, Ashland, Kentucky; vice-president for the northern district, M. G. GULLEY, of the Gulf Oil Corporation, Pittsburgh, Pennsylvania; secretary-treasurer, CHARLES BREWER, JR. (re-elected), of Godfrey L. Cabot, Inc., Charleston, West Virginia; editor, THURMAN H. MYERS, of the Carnegie Natural Gas Company, Pittsburgh, Pennsylvania.

Recent lecturers before the department of geology and geography, Northwestern University, Evanston, Illinois, were: W. H. VOSKUIL, mineral economist, Illinois Geological Survey, on "Economics of Mineral Production"; CLYDE P. ROSS, geologist, United States Geological Survey, on "Cinnabar Deposits of California"; D. F. HEWETT, geologist, United States Geological Survey, on "Mining Geology in the Western United States"; BENJAMIN B. COX, Vacuum Oil Company, on "Modern Petroleum Development"; J. H. MAXSON, California Institute of Technology, on "Geologic Studies in the Grand Canyon of the Colorado"; HAROLD T. STEARNS, United States Geological Survey, Hawaii, on "Hawaiian Volcanoes"; TAKEO WATANABE, University of Sapporo, Japan, "Japanese Geological Institutes"; and G. W. WHITE, University of New Hampshire, on "Novya Zemlya."

FREDERICK JAMES PACK, professor of geology at the University of Utah, died on December 2, 1938.

FREDERICK G. CLAPP has returned from the middle East and is continuing his consulting practice at 50 Church Street, New York City, specializing in the geology and appraisal of oil and gas properties.

JOHN N. BERG, of Tulsa, is in the employ of The Pure Oil Company geological department at Tulsa, Oklahoma.

A. I. LEVORSEN, past-president of the Association, lectured on "Trends in Petroleum Geology," before the geology club of the University of Iowa at Iowa City, November 14, 1938. On December 19, he spoke before the Tulsa Geological Society on "Some Frontiers of Petroleum Geology."

C. S. LAVINGTON addressed the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, December 19. His subject was "Notes on the Unconformity at the Top of the Benton."

E. T. MONSOUR, for the past 8 years paleontologist of the Standard Oil Company of New Jersey, has opened a consulting geologic laboratory with offices in the Chavanne Building, Lake Charles, Louisiana.

H. D. MISER delivered his presidential address before the Geological Society of Washington, D. C., December 14, on the subject, "Our Petroleum Supply." Miser is geologist in charge of the section of fuels of the United States Geological Survey.

E. KÜNDIG has been transferred from the Caribbean Petroleum Company at Caracas, Venezuela, to be geologist with the Astra Romano S. A., Câmpina, Roumânia.

R. J. RIGGS, of the Stanolind Oil and Gas Company, delivered his presidential address before the Tulsa Geological Society, January 9. His subject was "Review of Geology and Recent Developments in Illinois."

P. L. VANDOIT is general manager of the Fifteen Oil Company with headquarters at 611 West Building, Houston, Texas.

KENNETH R. PARSONS, recently with The Texas Company in Denver, Colorado, is with the California Arabian Standard Oil Company, Bahrein Island, Persian Gulf (via Baghdad, Iraq-Overland Route).

PAUL F. OSBORNE has been transferred from Midland, Texas, to be district geologist for the Tide Water Associated Oil Company at Mattoon, Illinois. His address is 1521 Charleston.

ANDREW N. MACKENZIE, general manager of the Cia. Consolidada de Petroleo at Caracas, Venezuela, for the past 12 years, has resigned his position and returned to his home at North Whittier Heights, California. His post office address is R.F.D. No. 2, Puente, California.

C. MAYNARD BOOS has resigned from the Independent Exploration Company and has moved from Mattoon, Illinois, to his home in Denver, Colorado, where he will begin a consulting practice in geophysics and general geology.

E. H. HUNT, J. M. KIRBY, and A. W. CULLEN spoke before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, on the subject, "Developments in 1938," January 9.

KATHARINE CARMAN has left the Felmont Corporation of Houston, Texas, to carry on independent geological work in the Illinois basin.

B. DYKSTRA has moved from the Shell Petroleum Corporation, Tulsa, to the Shell Oil Company, Los Angeles.

ROBERT L. BREEDLOVE, of the Arkansas Natural Gas Corporation, has moved from Tyler, Texas, to Shreveport, Louisiana.

RAYMOND LEIBENSPERGER, of the N. V. Nederlandsche Koloniale Petroleum Maatschappij, The Hague, has changed his address in care of Mrs. J. B. Hutchins, 38 Colonial Court, West New Brighton, Staten Island, New York.

H. J. MCCREADY, formerly with Seismic Explorations, Inc., is now an operator on a gravity meter crew with the Mott-Smith Corporation, 1504 Shell Building, Houston, Texas.

H. R. WOFFORD, JR., has changed his address from Petroleum Development (Western Arabia), Ltd., London, to the Tropical Oil Company, El Centro, Colombia, S.A.

FRANCIS P. SHEPARD has returned to the Geology Department, University of Illinois, Urbana, Illinois, after having been at the Scripps Institution of Oceanography, La Jolla, California.

PAUL A. WHITNEY, formerly at Bakersfield, California, is party chief for the General Geophysical Company, 2513 Gulf Building, Houston, Texas.

STANFORD L. ROSE, of The California Company, Denver, Colorado, has been transferred to India. His address is in care of Forbes, Forbes, and Campbell, Karachi, India.

JOHN G. BARTRAM, division geologist for the Stanolind Oil and Gas Company at Casper, Wyoming, has been transferred to the company's staff at Tulsa, Oklahoma.

The Instituto de Geología was founded in Caracas, Venezeula, and opened on September 5, 1938, with a selected registration of 24 students. The Institute is equipped with the latest apparatus for the investigation of geologic problems and offers a 4-year course leading to the bachelor's degree in geology. Though the Institute is a part of the Ministry of National Education, it has been organized by a committee of professional geologists from the Ministry of Industries, Geological and Mining Service. Members of the board of regents are: V. M. LÓPEZ, M. TELLO, P. I. AGUERREVERE, SANTIAGO E. AGUERREVERE, and G. ZULOAGA. The faculty includes: N. B. KNOX, technical director and professor of geology; ELY MENCHER, professor of paleontology; BELA MURAKOSY, professor of topography; and HERMAN KAISER, professor of chemistry. Many of the students have scholarships provided by the oil companies operating in Venezuela.

KIRK BRYAN, of Harvard University, is vice-president of the American Association for the Advancement of Science, and chairman of Section E, Geology and Geography.

T. WAYLAND VAUGHAN, emeritus professor of oceanography at the University of California, is president of the Geological Society of America.

RALPH W. CHANEY, professor of paleontology and head of the department at the University of California, is president of the Paleontological Society. A. S. ROMER, of Harvard, is vice-president, and R. R. SCHROCK, of the Massachusetts Institute of Technology, is treasurer.

MAXWELL NAYLOR SHORT, professor of petrography at the University of Arizona, is president of the Mineralogical Society of America.

ARTHUR C. VEATCH, consulting geologist, and previously geologist of the United States Geological Survey and head of the exploration department of the Sinclair Oil Company, died on December 24, at the age of 60 years.

E. H. WELLS, director of the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, died on January 7.

PERRY S. MCCLURE is geologist in charge of the new office of the Shell Petroleum Corporation at Evansville, Indiana.

G. C. CLARK, geologist with the Stanolind Oil and Gas Company, has been transferred from Amarillo to Fort Worth, Texas.

The Tulsa Geological Society has elected the following officers for 1939: president, ROBERT H. WOOD, of Wood Brothers, consulting geologists; first vice-president, CHARLES RYNIKER, of the Gulf Oil Corporation; second vice-president, J. D. MCCLURE, of the Barnsdall Oil Company; secretary-treasurer, M. H. BROWN, of the Darby Petroleum Corporation; editor, J. M. CLARK, of the Tide Water Associated Oil Company; members of the council, L. G. E. BIGNELL, of the *Oil and Gas Journal*, R. C. COFFIN, of the Stanolind Oil and Gas Company, and L. C. LAMAR, of the Carter Oil Company.

JOHN D. TODD, of the geological firm of Roper and Todd, addressed the Houston Geological Society recently on the Sparta-Wilcox trend.

HYRUM SCHNEIDER, former instructor in geology and mineralogy at the Colorado School of Mines, has been appointed professor of geology at the University of Utah to succeed the late FREDERICK J. PACK.

THERON WASSON, chief geologist of the Pure Oil Company, Chicago, recently discussed exploration and development of the Illinois basin region before the Investment Analysts' Club of Chicago.

CARL C. ADDISON, of the Pure Oil Company, Saginaw, Michigan, is the new president of the Michigan Geological Society; JED B. MAEBINS, of the Gulf Oil Corporation, Saginaw, is vice-president; R. P. GRANT, of the Michigan Geological Survey, Lansing, is secretary-treasurer; and HELEN M. MARTIN, Michigan Geological Survey, is business manager. Following the annual elections, which were held in the Park Hotel, St. Louis, the members attended a banquet and were entertained by colored motion pictures of the Northern Peninsula of Michigan and the Finger Lakes area of New York, as presented by CHARLES JOHNSON, consulting geologist, Mount Pleasant.

The Kansas oil-field nomenclature committee is composed of: ANTHONY FOLGER, chairman, district geologist for the Gulf Oil Corporation; JAMES I. DANIELS, of Pryor and Lockhart, Inc.; L. M. CLARK, district geologist for the Shell Petroleum Corporation; GRANVILLE TIERNEY, land man of the Amerada Petroleum Corporation; GEORGE H. NORTON, district geologist for the Atlantic Refining Company; HOWARD S. BRYANT, district geologist for the Skelly Oil Company; LEE H. CORNELL, of the geological staff of the Stanolind Oil and Gas Company; E. G. DAHLGREN, director of the oil and gas division of the Kansas Corporation Commission; and Z. E. STUCKEY, district geologist for the Cities Service Company.

J. C. KARCHER announces that the Coronado Corporation and the Coronado Exploration Corporation have removed their offices from 1311 Republic Bank Building to 406 Continental Building, Dallas, Texas.

The following Association members were lately elected to fellowship in the Geological Society of America: RONALD K. DE FORD, Argo Oil Company, Midland, Texas; GEORGE C. GESTER, Standard Oil Company (California), San Francisco; FRANK S. HUDSON, Shell Oil Company, Los Angeles; CLARENCE W. SANDERS, Shell Petroleum Corporation, Houston, Texas; J. O. G. SANDERSON, Home Oil Company, Calgary, Alberta.

ALBERT S. CLINKSCALES discussed the Anadarko basin before the Oklahoma City Geological Society at Oklahoma City, January 23.

C. E. NEEDHAM, professor of geology and paleontology at the New Mexico School of Mines, Socorro, has been appointed acting president to succeed E. H. WELLS, who died in January.

W. W. ORCUTT, vice-president of production of the Union Oil Company, Los Angeles, California, honorary member of the Association, has announced his retirement, effective December 31, 1938.

Newly elected officers of the South Louisiana Geological Society are: president, DEAN F. METTS, Humble Oil and Refining Company; vice-president, H. E. MCGLASSON, Stanolind Oil and Gas Company; secretary, G. O.

GRIGSBY, Stanolind Oil and Gas Company, 207 Weber Buidling, Lake Charles, Louisiana; treasurer, BAKER HOSKINS, Shell Petroleum Corporation.

L. E. WORKMAN and NORMAN PAYNE, of the subsurface division of the Illinois State Geological Survey, gave an illustrated talk on "Subsurface Geology of the Chester and Lower Mississippian of the Illinois Basin" at the meeting of the Illinois Geological Society, at the U. S. Grant Hotel, Mattoon, Illinois, January 13.

The following were elected officers of the Illinois Geological Society at Mattoon, January 13: president, VERNER E. JONES, Magnolia Petroleum Company, Mattoon; vice-president, M. W. FULLER, Carter Oil Company, Mattoon; secretary-treasurer, ELMER W. ELLSWORTH, of W. C. McBride, Inc., Centralia, Illinois. Approximately 100 geologists attended the meeting from Illinois, Indiana, Kentucky, and Missouri.

E. DEGOLYER and LEWIS W. MACNAUGHTON announce that they will continue to serve as appraisers of oil companies and properties and consultants in petroleum geology under the partnership name of DeGolyer and MacNaughton with offices in the Continental Building, Dallas, Texas.

The University of Oklahoma held a short course on "Aerial Photographic Mapping and Geological Exploration," at Norman, February 17 and 18, through the efforts of FRANK ARMON MELTON, associate professor in the department of geology, and the Extension Division. Lecturers were: DONALD C. BARTON, Humble Oil and Refining Company, Houston, president of the A.A.P.G.; FRANK G. EVANS, Shell Petroleum Corporation, Houston; MARSHALL S. WRIGHT, special adviser on aerial photography to the Secretary of Agriculture, Washington, D. C.; T. P. PENDELTON, U. S. Geological Survey, Washington, D. C.; LOUIS DESJARDINS, Aero Explorations Company, Tulsa; J. C. CARPENTER, U. S. Bureau of Public Roads, Fort Worth; ERIC HAQUINIUS, Brazos River Conservation and Reclamation District, Mineral Wells; FRANK A. MELTON, University of Oklahoma.

An Association member who is statistically minded submits the following enumeration of names showing that the Clarks lead in the A.A.P.G. membership list: Clark, 22; Smith, 20; Brown, 17; Miller, 17; Jones, 13; Johnson or Johnston, 13; Davis or Davies, 12; Thompson, 11; Wood or Woods, 11; Anderson, 9; Morgan, 9; Thomas, 9; Allen, 8; Taylor, 8; Scott, 8.

HEATH M. ROBINSON, oil geologist, announces removal of his office from 406 Continental Building to 1406 Gulf States Building, Dallas, Texas.

W. B. EMERY, geologist with the Ohio Oil Company, has moved from Casper, Wyoming, to Findlay, Ohio.

New officers of the Fort Worth Geological Society are: president, J. EARLE BROWN, consulting geologist; vice-president, J. H. MARKLEY, of the Texas Company; secretary-treasurer, VERNON LIPSCOMB, of the Pure Oil Company.

GUY M. RATLIFF, geologist with the Luling Oil and Gas Company of San Antonio, has resigned to enter consulting practice. He may be addressed at 259 West Wildrose Drive, San Antonio, Texas.

R. F. BAKER, manager of The Texas Company foreign geological department, New York, is in Egypt.

CLAUDE C. ALBRITTON, professor of geology at Southern Methodist University, Dallas, Texas, talked on "The Geology of the Malone Mountains," at the January 19 meeting of the Dallas Petroleum Geologists.

J. R. WILLIAMS, geologist with J. V. Wicklund Development Company, has moved from Urbana, Illinois, to Owensboro, Kentucky.

J. D. TOMPKINS, of the Acme Oil and Royalty Company, has been transferred from Midland, Texas, to Houston.

MARGARET FULLER BOOS presented a paper on "Some Structures in the Front Range West of the Foothills," before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, January 23.

ARTHUR J. TIEJE, of Ángeles, California, has returned from a trip around the world, visiting the Pladjoe oil fields, Sumatra, the Yenanyaung field in Burma and several smaller fields, and bringing back considerable material from the Eocene of India.

JOHN YOUNG SNYDER, long a prominent consulting geologist of Shreveport, Louisiana, president of the Association in 1929, died on January 10, after an illness of several years.

IRA H. CRAM, secretary-treasurer of the Association, and district geologist for the Pure Oil Company at Tulsa, Oklahoma, delivered several lectures on petroleum geology at the University of Kansas in January.

A. I. LEVORSEN, past-president of the Association, and consulting geologist of Tulsa, Oklahoma, gave four lectures on petroleum geology at the University of Minnesota in February.

ROBERT ROTH, geologist for the Humble Oil and Refining Company at Wichita Falls, Texas, has been elected a fellow of the Geological Society of America.

New officers of the Rocky Mountain Association of Petroleum Geologists are: president, WARREN O. THOMPSON; 1st vice-president, DAVID B. MILLER; 2nd vice-president, HAROLD N. HICKEY; secretary-treasurer, NINETTA DAVIS, 224 U. S. Customs Building, Denver, Colorado.

A. I. LEVORSEN, past-president of the Association, addressed the Shreveport Geological Society and the Houston Geological Society last month.

Through error in the January *Bulletin*, the officers of the West Texas Geological Society were not correctly listed. The newly elected officers of this society are: president, BERTE R. HAIGH, University Lands, Midland; vice-president, W. C. FRITZ, Skelly Oil Company, Midland; secretary-treasurer, J. E. SIMMONS, Continental Oil Company, Midland.

The officers of the Midland Geological Society, a subsidiary society of the West Texas Geological Society, are: president, ROBERT E. KING, Shell Petroleum Corporation; vice-president, H. D. PENNEL, Amerada Petroleum Corporation; secretary-treasurer, W. Y. PENN, consulting geologist.

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404 Haas Building
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A. I. LEVORSEN
Petroleum Geologist
221 Woodward Boulevard
TULSA OKLAHOMA

GEO. C. MATSON
Geologist
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Consultant and Contractor in Geological and Geophysical Exploration
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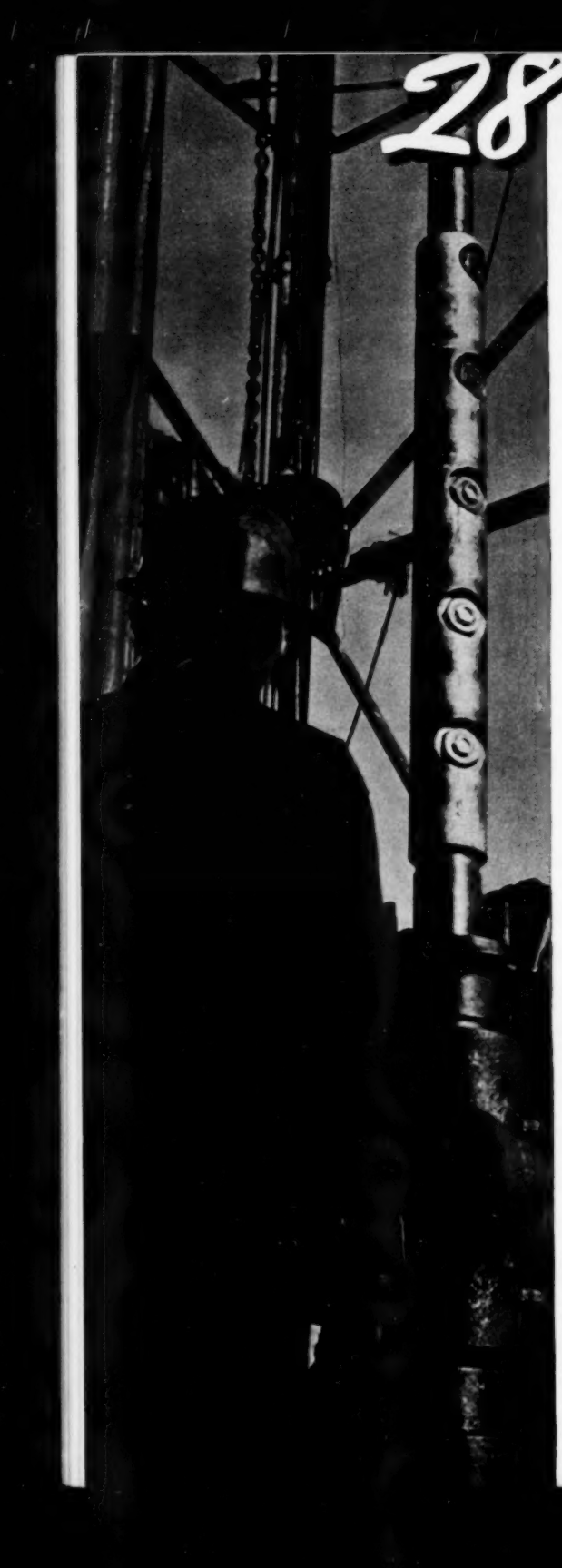

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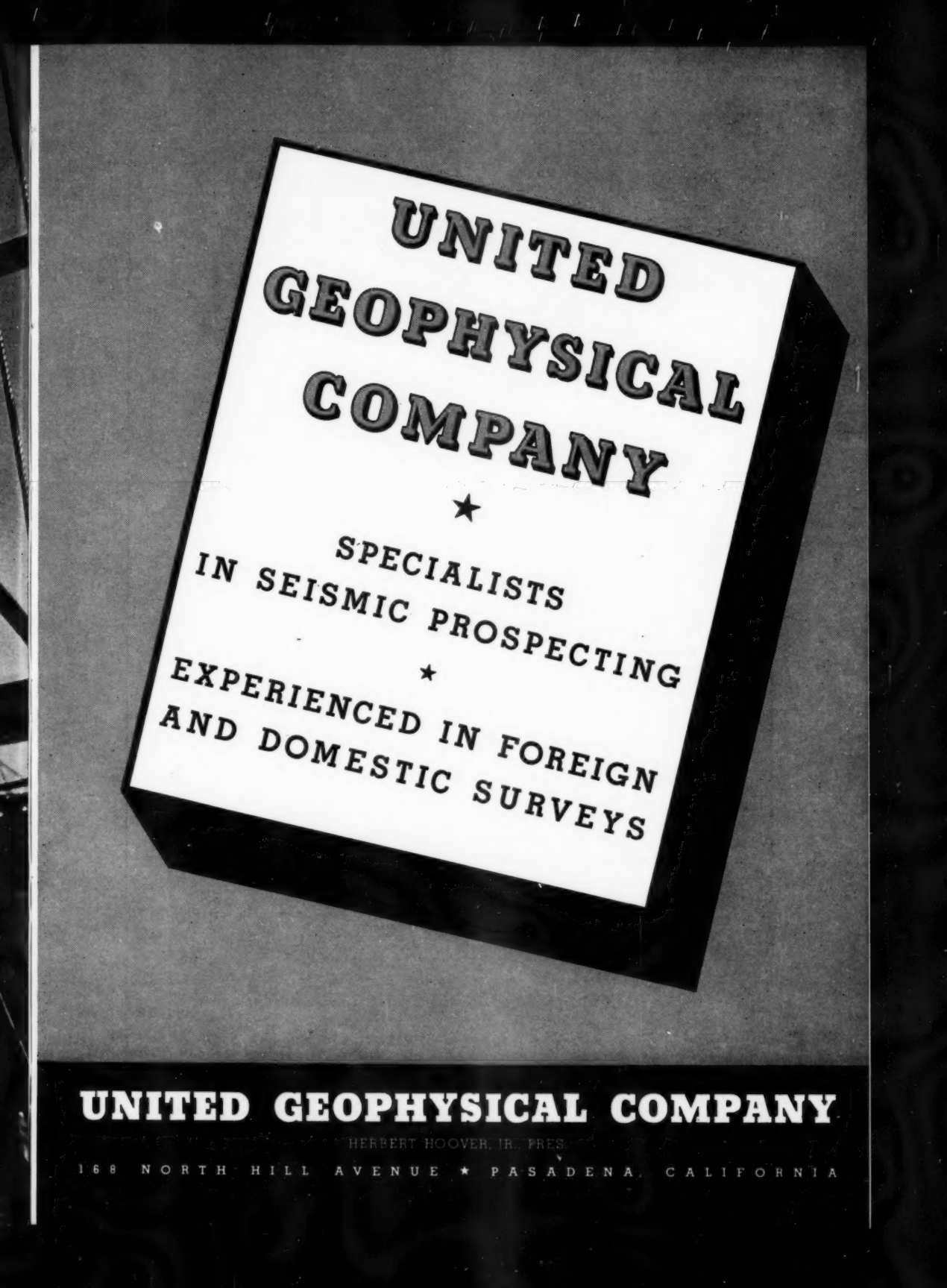

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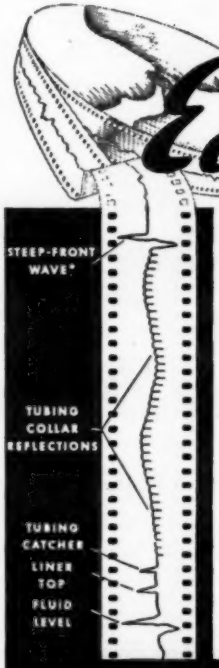

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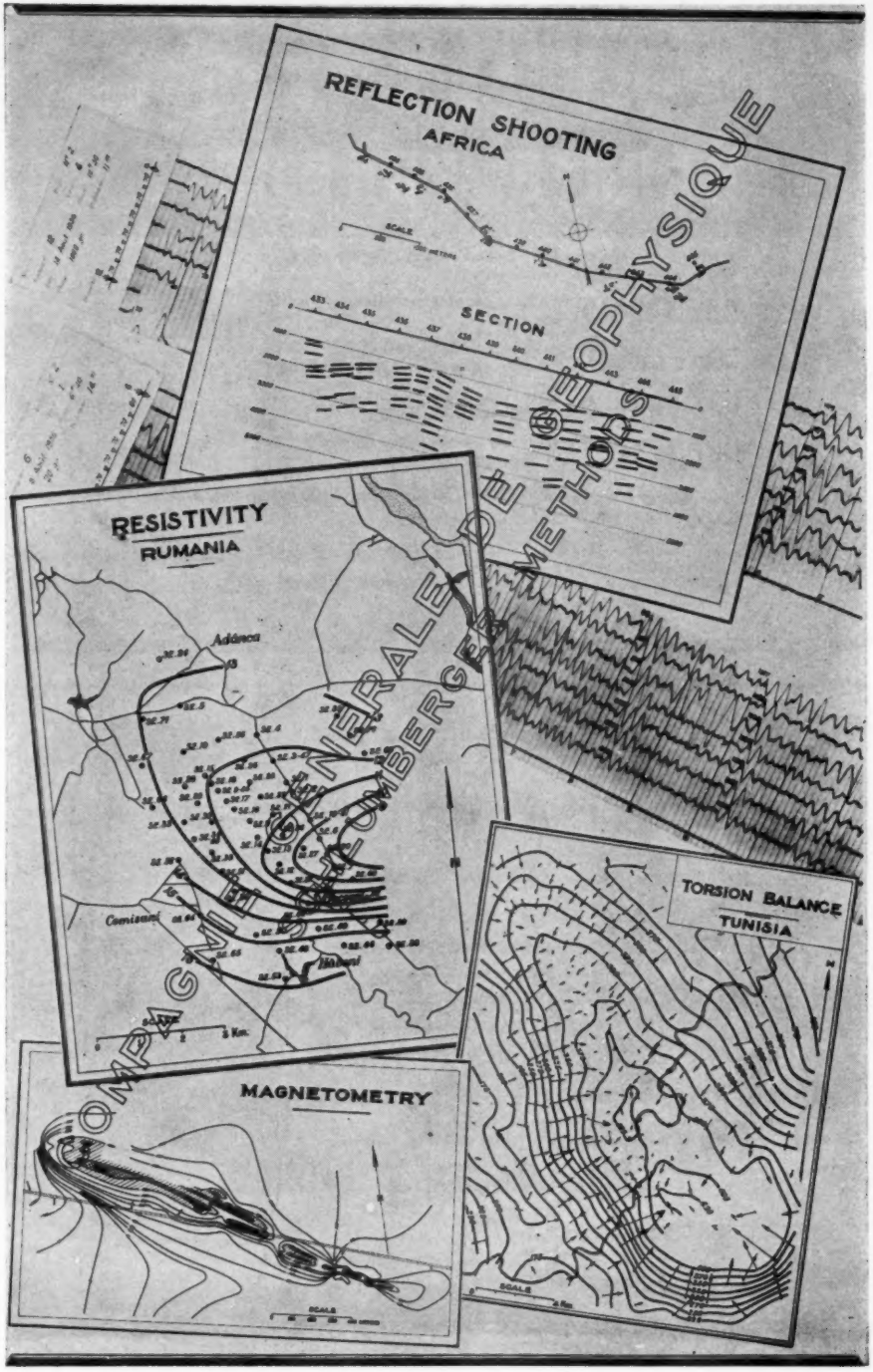
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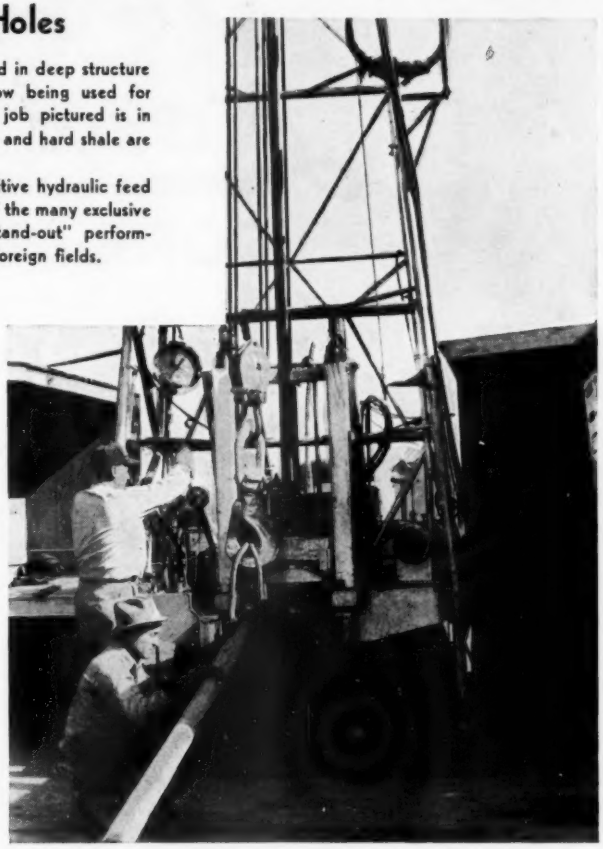

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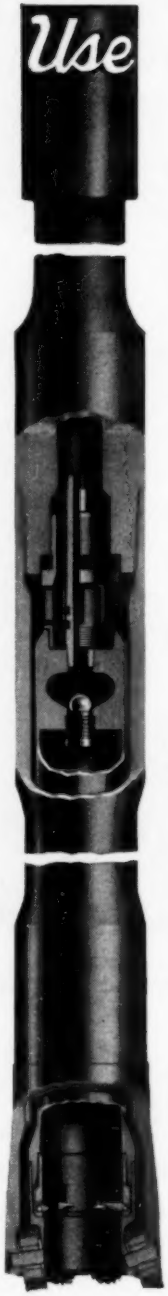

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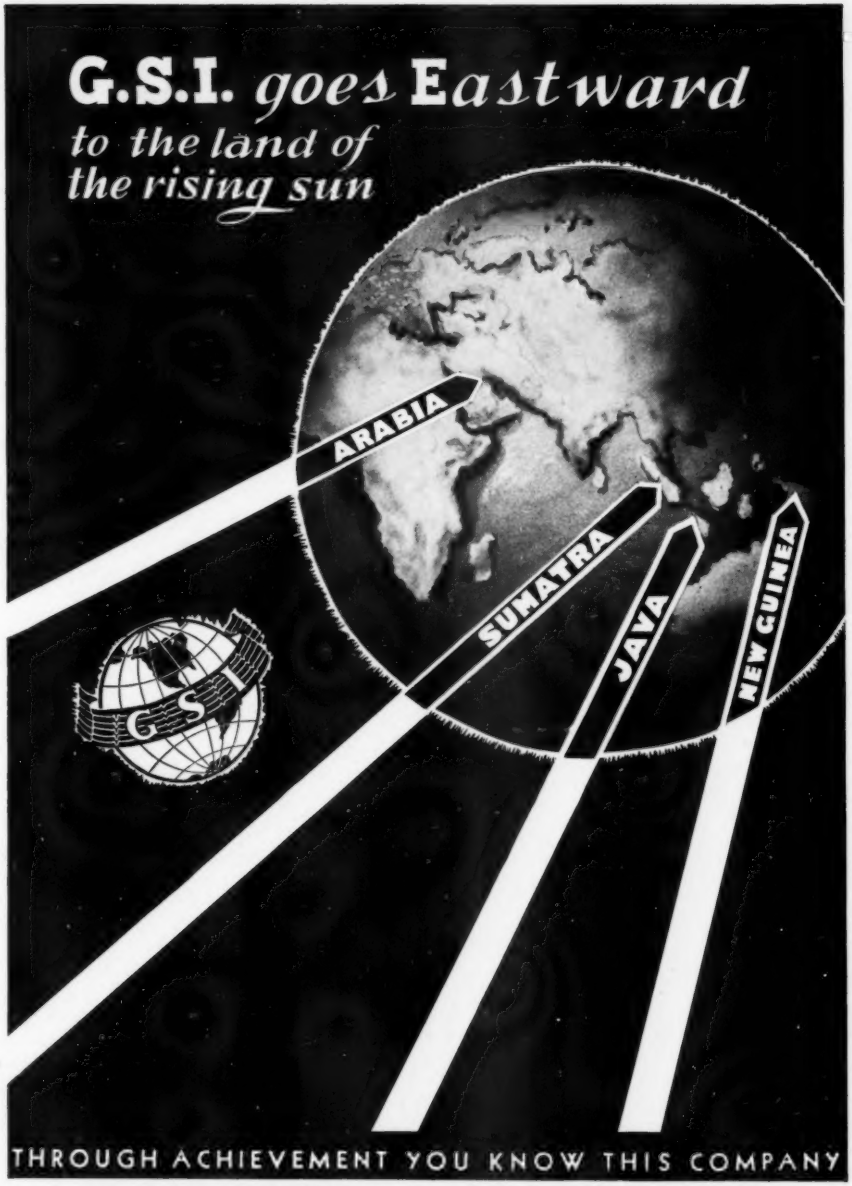
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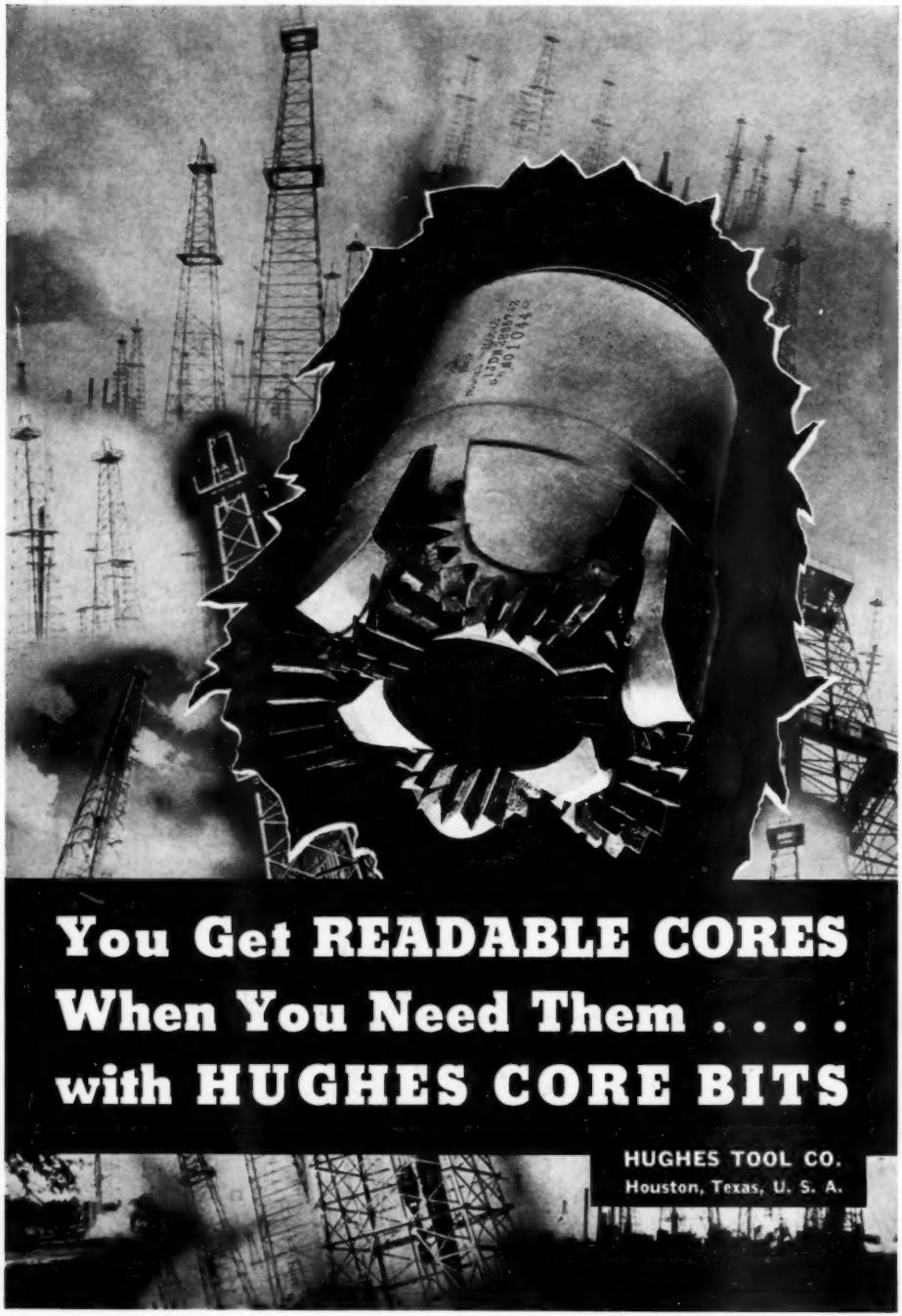
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